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NAVAL ARCTIC MANUAL
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NAVAL ARCTIC MANUAL

ATP-17(A)

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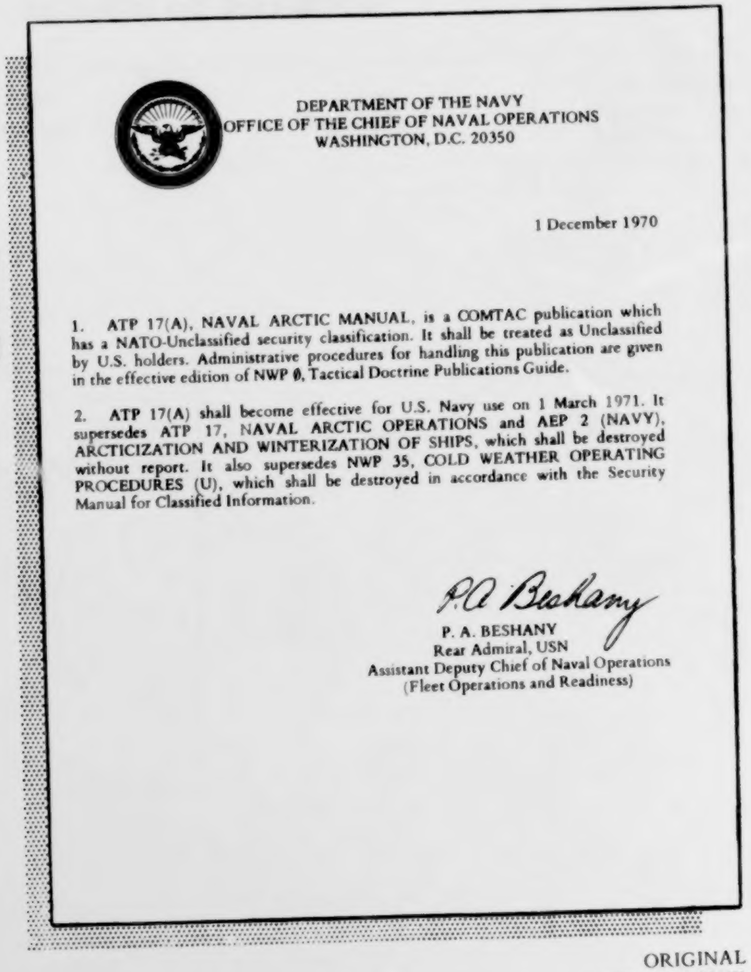

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TABLE OF CONTENTS

Page No.

List of Figures XV
List of Tables XVIII
Preface XIX
Arctic Ocean Plotting Chart (Fold-out) . . . . (End of book)

CHAPTER 1 – THE ARCTIC ENVIRONMENT

101 General Description 1-1
102 Limits of Arctic Lands 1-4
103 Geology and Geomorphology 1-4
104 The Physiographic Elements of North America, Eurasia and the North Atlantic Islands 1-8
105 Permafrost and Terrain 1-10
106 Permanent Land Ice 1-11
107 Beaches and Cliffs 1-14
108 Details of Coastal Topography 1-16

CHAPTER 2 – CLIMATE

201 Introduction 2-1
202 Air Pressure 2-4
203 Principal Tracks of Cyclones and Synoptic Systems 2-4
204 Wind 2-11
205 Temperature 2-16
206 Fog and Visibility 2-21
207 Cloud 2-22
208 Precipitation 2-22
209 References 2-23

Page No.

CHAPTER 3 – OCEANOGRAPHY

SECTION I – GENERAL DESCRIPTION

301 Definition 3-1
302 Bathymetry 3-1
303 Water Masses 3-4
304 Currents 3-6
305 Advection Boundaries 3-11

SECTION II – REGIONAL OCEANOGRAPHY

306 Introduction 3-12
307 The Sea of Okhotsk 3-12
308 The Bering Sea and the Bering Strait 3-13
309 The Chukchi Sea 3-18
310 Western North American Waters 3-27
311 Eastern North American Waters 3-27
312 Hudson Bay, Foxe Basin and the Labrador Sea . . 3-30
313 Northeast Atlantic Waters 3-46
314 Eurasian Coastal Waters 3-57
315 Eastern Siberian Coastal Waters 3-59
316 Central Polar Basin 3-60

CHAPTER 4 – SEA ICE

SECTION I – GENERAL DESCRIPTION

401 Introduction 4-1

TABLE OF CONTENTS

Page No.

402 Ice Formation 4-2
403 Structure and Properties of Sea Ice 4-3
404 Annual Ice Cycle 4-4
405 Occurrence of Sea Ice 4-5
406 Ice Forecasting 4-5
407 Other Ice Encountered at Sea 4-7
408 References 4-7
409 Ice Glossary 4-7

SECTION II – REGIONAL ICE CONDITIONS

410 Introduction 4-22
411 Bering Sea and Sea of Okhotsk 4-22
412 Chukchi Sea 4-23
413 Beaufort Sea 4-23
414 Laptev and Eastern Siberian Seas 4-26
415 Barents Sea 4-28
416 Kara Sea 4-28
417 Approaches to the Lincoln Sea (Nares Strait) . . . 4-29
418 Baffin Bay and Davis Strait 4-29
419 Northern Canadian Arctic Archipelago (Queen Elizabeth Islands) 4-30
420 Southern Canadian Arctic Archipelago (Including Parry Channel) 4-31
421 Hudson Strait and Bay 4-36
422 Foxe Basin 4-37
423 Labrador Sea and Newfoundland Waters 4-38
424 Gulf of St. Lawrence 4-38

Page No.

425 Northeast Atlantic and East and North Greenland . 4-39
426 The Polar Basin 4-40

CHAPTER 5 – GENERAL PREPARATIONS FOR ARCTIC OPERATIONS

501 General 5-1
502 Painting and Lubrication 5-1
503 Covers for Equipment 5-1
504 Boats 5-2
505 Mooring Lines and Anchor Gear 5-2
506 Towing 5-3
507 Snow and Ice Removal 5-3
508 Superstructure Icing 5-5
509 Icing on Conning Position Windows 5-5
510 Cargo Handling and Unloading 5-7
511 Watchbills 5-7
512 Drying and Stowage Areas for Cold Weather Clothing 5-7

CHAPTER 6 – HULL, ENGINEERING AND ELECTRICAL

601 General 6-1
602 Hull Structure 6-1
603 Obstructions 6-1
604 Propellers and Shafting 6-1
605 Exposed Piping and Scuppers 6-1
606 Damage and Repairs in the Ice 6-1
607 Stowage Space Requirements 6-2

TABLE OF CONTENTS

Page No.

608 Refrigeration Space 6-2
609 Fresh Water Supply 6-2
610 Salt Water Supply 6-3
611 General Instructions for Machinery. 6-3
612 Exposed Equipment. 6-4
613 General Instructions. 6-4
614 Steam Pipes and Steam Heating. 6-7
615 Electrical Heating 6-9
616 Ventilation 6-9
617 Insulation. 6-9
618 Tank Vents. 6-10
619 Sirens and Air Horns 6-10
620 Lookout and Conning Positions. 6-10
621 Short Stay in Harbour (Up to 48 Hours) 6-10
622 Long Stays in Harbour and Refits in Cold Weather 6-11
623 Fresh Water 6-12
624 Gas Cylinders 6-12
625 Preparations Applicable to Amphibious and Auxiliary Craft 6-12
626 Main Electrical Supply 6-14
627 Lighting 6-14
628 Batteries. 6-15

CHAPTER 7 – WEAPONS

701 De-Icing 7-1
702 Guns 7-1
703 Covers 7-1
704 Transferable Gun Mountings 7-1

Page No.

705 Non-Transferable Mountings 7-1
706 Fire Control Directors 7-3
707 Recoil Mechanisms 7-3
708 Aircraft Guns 7-3
709 Gunsights and Aircraft Fire Control Equipment . . 7-4
710 Bomb Sights and Bomb Directors. 7-4
711 Ammunition 7-4
712 Lubricants 7-4
713 Torpedoes and Torpedo Tubes 7-5
714 Mines. 7-5
715 Minesweeping Gear 7-5
716 Missiles and Missile Systems 7-5
717 Ahead-Throwing Weapons 7-6

CHAPTER 8 – ELECTRONICS

801 General Requirements 8-1
802 Exposed Electronic Equipment 8-1
803 Ice on Antennae 8-1
804 Variable Speed Antennae 8-2
805 Slow-Moving Mechanical Parts 8-2
806 Covered Cables 8-2
807 Electric Installations. 8-2
808 Telephones and Microphones. 8-2
809 Communications Equipment 8-2
810 Effective Radiation Characteristics 8-4
811 Care of Equipment in Low Temperatures 8-4
812 Underwater Electronic Equipment 8-4
813 Portable Power Sources (for Electronic Equipment) 8-4

TABLE OF CONTENTS

Page No.

814 Maintenance (Personnel Precautions) 8-5

CHAPTER 9 – PERSONNEL

901 Introduction 9-1
902 Training 9-1
903 Food 9-1
904 Fresh Water 9-2
905 Clothing 9-2
906 Ship Habitability 9-2
907 Disease Prevention 9-4
908 Mental Health 9-4
909 Medical–General 9-4
910 Frostbite 9-4
911 Immersion Foot 9-5
912 Hypothermia 9-5
913 Snowblindness 9-7

CHAPTER 10 – GENERAL OPERATIONS

1001 Introduction 10-1
1002 Icebreakers 10-1
1003 Typical Modern Polar Icebreaker 10-3
1004 Ships 10-3
1005 Submarines 10-4
1006 Air-Cushion Vehicles 10-5
1007 Diving 10-7

Page No.

CHAPTER 11 – SHIP-HANDLING IN ICE AND ICE SEAMANSHIP

1101 Introduction 11-1
1102 Non-Ice-strengthened Ships 11-1
1103 Indications of Ice 11-1
1104 Signs of Open Water 11-2
1105 Icebergs 11-2
1106 Entering the Ice 11-3
1107 Speed of Ships Working in Ice 11-5
1108 Working through Ice 11-6
1109 Convoying in Ice 11-9
1110 Types of Convoy 11-9
1111 Distance between Ships 11-11
1112 Course and Speed of Convoy 11-12
1113 Conducting through Ice 11-12
1114 Signalling between Icebreakers and Escorted Ships 11-13
1115 Stopped Icebreaker – Red Warning Lights and Sound Signal 11-15
1116 Breaking Out Ships 11-15
1117 Inadvisability of Towing 11-16
1118 Replenishment in Ice 11-16
1119 Anchoring 11-16

CHAPTER 12 – ARCTIC NAVIGATION, NAVIGATIONAL AIDS AND PILOTAGE

1201 General 12-1

TABLE OF CONTENTS

Page No.

1202 Charts and Sailing Directions 12-1
1203 General Reference Books 12-1
1204 Chart Projections 12-1
1205 Polar Grid 12-1
1206 Magnetic Compasses 12-1
1207 Gyro Compasses 12-2
1208 Azimuths 12-3
1209 Celestial Compasses 12-3
1210 Dead Reckoning 12-3
1211 Astronomical Observations 12-4
1212 Sunrise, Sunset and Twilight Phenomena 12-4
1213 Abnormal Refraction 12-4
1214 Echo-Sounder 12-6
1215 Logs 12-6
1216 Electronic Aids to Navigation 12-6
1217 Radar as a Fixing Aid 12-7
1218 Radar and Sonar for Ice Detection 12-8
1219 References 12-9

CHAPTER 13 – ARCTIC AVIATION

1301 Introduction 13-1
1302 Air Navigation 13-1
1303 Instruments 13-2
1304 Electronic Equipment 13-2
1305 Electrical 13-3
1306 Servicing Aircraft in Cold Temperatures 13-3
1307 Refuelling 13-3
1308 Oil Replenishment 13-4

Page No.

1309 Cold Starting Piston Engines 13-4
1310 Engine Lubrication 13-5
1311 Piston Engine Shut-down and Re-starting 13-5
1312 External Heating 13-5
1313 Propellers 13-6
1314 Cold Starting Jet Engines 13-6
1315 Low Temperature Fuel Combustion 13-6
1316 Condensation 13-7
1317 Airframes 13-7
1318 Flight Operations 13-8
1319 Preflight 13-10
1320 Preparation for Flight 13-10
1321 Heating 13-10
1322 Anti-Icing 13-11
1323 De-Icing 13-11
1324 Rotary Wing Aircraft Operation 13-11
1325 Fixed Wing Ski Operation 13-12
1326 Aircraft Operations 13-15

CHAPTER 14 – SUBMARINE AND ANTI-SUBMARINE OPERATIONS

SECTION I – SUBMARINE OPERATIONS

1401 Material Readiness 14-1
1402 Under-Ice Procedures 14-2
1403 Surfacing in Pack Ice 14-2
1404 Surfacing Techniques 14-4

TABLE OF CONTENTS

Page No.

1405 Precautions on the Surface . . . 14-5
1406 Diving in an Ice Area . . . 14-5

SECTION II – ANTI-SUBMARINE WARFARE

1407 General . . . 14-5
1408 Detection Capabilities . . . 14-6
1409 Shallow Water Limitations on Submarines . . . 14-6
1410 Submarine versus Submarine . . . 14-6

CHAPTER 15 – AMPHIBIOUS OPERATIONS IN THE ARCTIC

1501 Introduction . . . 15-1
1502 Marginal Ice Areas . . . 15-1
1503 Marginal Ice Operations . . . 15-2
1504 Sea, Surf and Swell . . . 15-2
1505 Effects of Terrain on Amphibious Assaults . . . 15-3
1506 Effects of Climate and Weather . . . 15-3
1507 Other Special Considerations . . . 15-4

CHAPTER 16 – BEHAVIOUR OF ELECTRONIC AND SONIC EMISSIONS

SECTION I – RADIO COMMUNICATIONS IN THE ARCTIC

1601 Introduction . . . 16-1
1602 Communications Procedures . . . 16-1

Page No.

1603 Ionospheric Disturbances . . . 16-2

SECTION II – UNDERWATER SOUND IN THE ARCTIC

1604 Introduction . . . 16-5
1605 Underwater Sound Transmission . . . 16-5
1606 Reverberation . . . 16-7
1607 Ambient Noise . . . 16-8
1608 Range Prediction . . . 16-9

CHAPTER 17 – SURVIVAL

1701 Introduction . . . 17-1
1702 Fear . . . 17-1
1703 Cold . . . 17-3
1704 Man Overboard . . . 17-3
1705 Abandon Ship . . . 17-4
1706 Immersion Suits . . . 17-4
1707 Helicopter Survival Equipment . . . 17-5
1708 Emergency Aircraft Landings in the Arctic . . . 17-5
1709 Ocean Survival . . . 17-8
1710 Anoxia . . . 17-9
1711 Carbon Monoxide Poisoning . . . 17-9
1712 Firearms . . . 17-10
1713 Dangerous Arctic Animals . . . 17-10
1714 Insects . . . 17-11
1715 Wintering-In . . . 17-11
1716 Search and Rescue . . . 17-13

LIST OF FIGURES

Page No.

1–I Boundaries of the Arctic and Sub-Arctic Environments 1-3
1–II Geological Structure of the Circumpolar World. . 1-5
1–III Mt. Kiska – An Active Volcano in the Aleutian Island Chain. 1-7
1–IV Coastal Plain, Western Banks Island 1-8
1–V Eglinton Fiord, and Sam Ford Fiord, Baffin Island (An example of fiord and alpine geomorphology) 1-10
1–VI Chamberlain Glacier entering Wolstenholme Fiord (Northwest Greenland). 1-12
1–VII Contemporary Arctic Glaciers 1-13
1–VIII Ice-shove Ridges, Nansen Sound, Northern Canada 1-14
1–IX The Labrador Coast 1-15

◆

2–I Observing Stations. 2-2
2–II Mean Sea Level Pressure – January 2-5
2–III Mean Sea Level Pressure – July. 2-6
2–IV Principal Tracks of Cyclones – January. 2-7
2–V Principal Tracks of Cyclones –July. 2-8
2–VI Mean Air Temperature— January. 2-18
2–VII Mean Air Temperature – July 2-19
2–VIII Mean Cloud Amount in Percentages – January. . 2-25
2–IX Mean Cloud Amount in Percentages – July. . . . 2-26

Page No.

Arctic Ocean:

3–I Bathymetry 3-2
3–II Vertical Distributions of Temperature and Salinity at Six Localities. 3-5
3–III Mean Surface Salinity – Summer. 3-7
3–IV Composite Surface Circulation. 3-9
3–V Composite Atlantic Layer Circulation 3-10
3–VI Sea of Okhotsk – Bathymetry, Surface Currents, and July Mean Temperatures. 3-14
3–VII Bathymetry of the Bering Sea 3-15
3–VIII Bering Sea: Currents and Physiographic Regions. 3-16
3–IX Bathythermograph Samples in the Bering Sea North of the Aleutians – Summer Conditions. 3-20
3–X Bering Sea Surface Temperature – February (° F) 3-21
3–XI Bering Sea Surface Temperature – August (° F). 3-22
3–XII Bathymetry of Chukchi Sea. 3-23
3–XIII Chukchi Sea – Average Surface Currents. 3-24
3–XIV Chukchi Sea – Average Sea Surface Temperature in August (° F) 3-25
3–XV Bathythermograph Samples in the Chukchi Sea – Summer Conditions in the Ice Pack. . . . 3-26
3–XVI General Circulation – Eastern North American Waters. 3-31
3–XVII Bathythermograph Samples – Eastern North American Waters. 3-32
3–XVIII Location of Bathythermograms – Eastern North American Waters (refer to Figure 3–XVII) . . . 3-34

LIST OF FIGURES

Page No.

3–XIX Bathymetry – Labrador Sea and Newfoundland Waters . . . 3-38
3–XX General Circulation – Hudson Strait, Hudson Bay and Foxe Basin . . . 3-39
3–XXI General Circulation – Labrador Sea, Newfoundland Waters and the Gulf of St. Lawrence . . . 3-40
3–XXII Distribution of Surface Temperatures in August (° C) in the Labrador Sea, Newfoundland Waters and the Gulf of St. Lawrence . . . 3-41
3–XXIII Distribution of Surface Temperatures in March (° C) in the Labrador Sea, Newfoundland Waters and the Gulf of St. Lawrence . . . 3-42
3–XXIV Examples of Winter and Summer Bathythermograms – Hudson Bay, Foxe Basin and the Labrador Sea . . . 3-43
3–XXV Locations of Bathythermograms – Hudson Bay, Foxe Basin and the Labrador Sea (refer to Figure 3–XXIV) . . . 3-45
3–XXVI Depth Contours in Metres – Norwegian and Adjacent Seas . . . 3-49
3–XXVII Water Masses – Norwegian and Adjacent Seas . . 3-50
3–XXVIII Surface Temperature Distribution in February (° C) – Norwegian and Adjacent Seas . . . 3-51
3–XXIX Surface Temperature Distribution in August (° C) – Norwegian and Adjacent Seas . . . 3-52
3–XXX One Hundred Ten Fathom (201 m.) Temperature Distribution (° C) – Norwegian and Adjacent Seas . . . 3-53

Page No.

3–XXXI Surface Currents – Norwegian and Adjacent Seas . . . 3-54
3–XXXII Surface Currents – Barents and Kara Seas . . . 3-58
3–XXXIII Physiographic Regions of the Arctic Ocean and Adjacent Seas . . . 3-62
3–XXXIV Topographic Profile Across the Arctic Ocean . . . 3-65
3–XXXV Earthquakes in the Arctic, January '55 – March '64 . . . 3-67
3–XXXVI Representative Examples of Sound Velocity in the Greenland Sea . . . 3-68

◆

4–I The Formation of Sea Ice . . . 4-2
4–II The General Pattern of Ice Movement in the Arctic Ocean . . . 4-6
4–III Freshwater Ice from a Glacier (Iceberg) . . . 4-7
4–IV Spongy White Ice Lumps which Retain their Characteristic Shape only when Immersed ("Shuga") . . . 4-17
4–V Nilas Forming in a Lead through Rafted Grey and Grey-White Ice . . . 4-17
4–VI First Year Ice with Ridges and Hummocks . . . 4-18
4–VII Close Pack Ice Composed of Ice Cakes and Small and Medium Floes of Thick First Year Ice . . . 4-18
4–VIII Ice Island Fragments in Second Year Ice . . . 4-19
4–IX Old Ice (Multi-Year) in Varying Floe Sizes . . . 4-19
4–X Flaw Polynya Outside Fast Ice . . . 4-20

LIST OF FIGURES

Page No.

4–XI An Iceberg in Compact Pack Ice 4-20
4–XII Rotten Ice – A Smooth Even Ice Cover that has Very Nearly Melted 4-21
4–XIII Iceberg and Growlers 4-21
4–XIV Bering Sea: Approximate Monthly Limits of Pack Ice for November-February 4-24
4–XV Bering Sea: Approximate Monthly Limits of Pack Ice for March-June 4-25
4–XVI Freeze-up Season, Baffin Bay-Labrador Sea Area (Average Limit of 0.1 Concentration of Sea Ice) 4-32
4–XVII Break-up Season, Baffin Bay-Labrador Sea Area (Average Limit of 0.1 Concentration of Sea Ice) 4-33
4–XVIII Navigation Conditions, East and West Coasts of Greenland 4-34
4–XIX Baffin Bay Iceberg Census, August 1949 (From USCG Information) 4-35
4–XX Light Summer Ice Conditions, Beaufort Sea to Lincoln Sea (1-15 September) 4-43
4-XXI Heavy Summer Ice Conditions, Beaufort Sea to Lincoln Sea (1-15 September) 4-45
4–XXII Typical Winter Ice Conditions, Beaufort Sea to Lincoln Sea (February) 4-47
4–XXIII Light Summer Ice Conditions, Lincoln Sea to Laptev Sea (1-15 September) 4-49

Page No.

4–XXIV Heavy Summer Ice Conditions, Lincoln Sea to Laptev Sea (1-15 September) 4-51
4–XXV Typical Winter Ice Conditions, Lincoln Sea to Laptev Sea (February) 4-53
4–XXVI Light Summer Ice Conditions, Laptev Sea to Beaufort Sea (1-15 September) 4-55
4–XXVII Heavy Summer Ice Conditions, Laptev Sea to Beaufort Sea (1-15 September) 4-57
4–XXVIII Typical Winter Ice Conditions, Laptev Sea to Beaufort Sea (February) 4-59
4–XXIX Drift Track of Ice Station Arlis II 4-61

◆

16–I Sunspot Activity 16-2
16–II The Ionosphere 16-3
16–III North Polar Auroral Zone 16-4
16–IV Underwater Sound Transmission 16-6

◆

17–I Survival Chart 17-1
17–II Wind Chill Temperature Chart 17-2

LIST OF TABLES

Page No.

1–I The Arctic Land Environment (by Political Units) 1-2

◆

2–I Observing Station Locations. 2-3
2–II Frequency Distribution of Wind Speed over Central Arctic Ocean 2-11
2–III Average Surface Wind Speed and Most Prevalent Direction 2-12
2–IV Frequency of "Gales" per Month and Year . . 2-15
2–V Average Departure from the Normal of Monthly Mean Temperature (°C.) 2-20
2–VI Mean Number of Days with Fog per Month and Year 2-27
2–VII Mean Monthly and Annual Precipitation 2-29

◆

3–I Fathoms / Metres Conversion Table 3-3
3–II Temperature and Salinity Characteristics of the Water Masses of the European and American Arctic and Sub-Arctic Seas 3-48

PREFACE

"The success of a polar expedition principally depends upon the preparations which were made before the expedition started out." – Fridtjof Nansen

This Naval Arctic Manual is intended to provide basic information to those engaged in Arctic operations who are unfamiliar with the environment and the operational problems associated with the environment. It is directed specifically towards the commanding officer at sea, and the operational planner ashore.

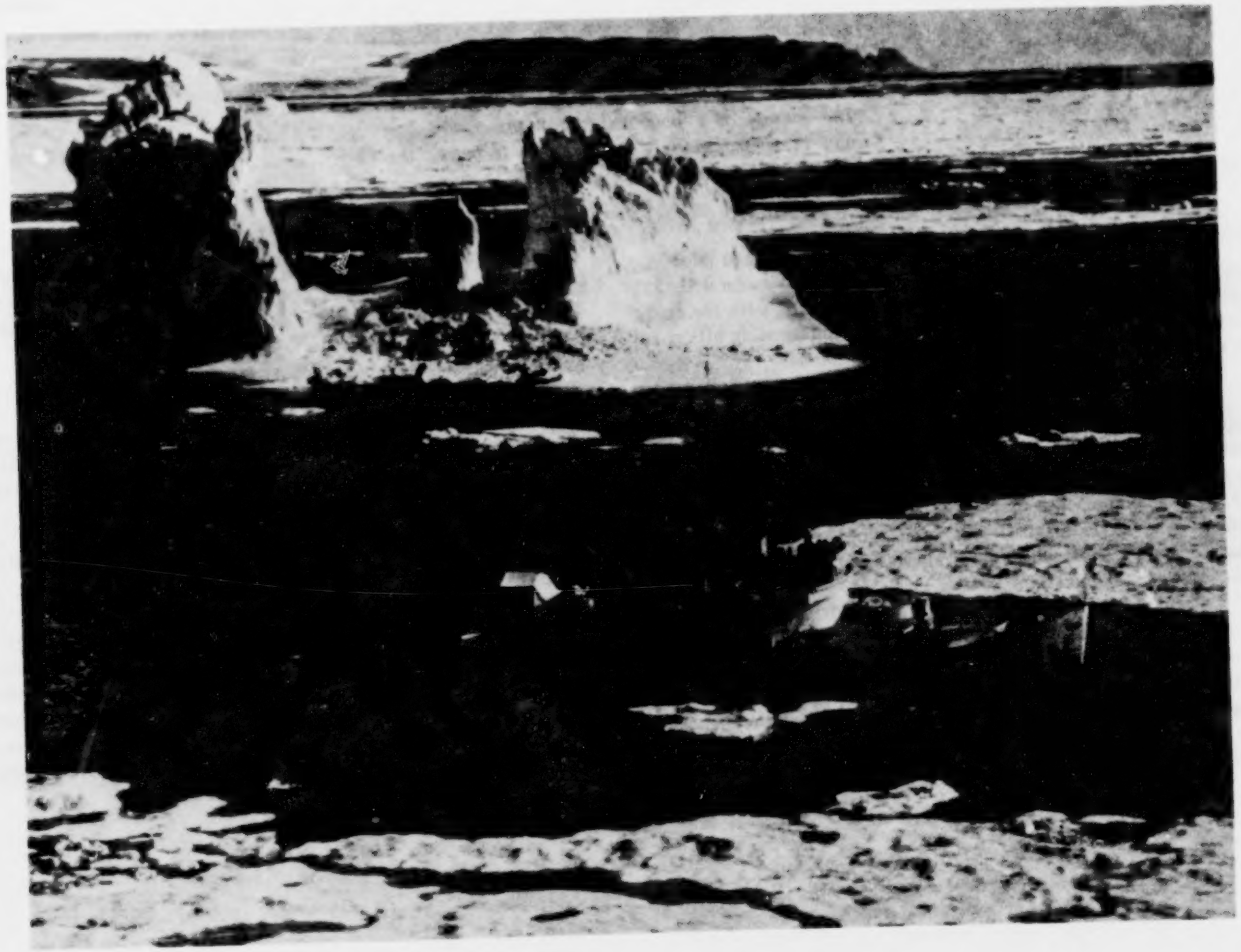
In the past decade a great wealth of new knowledge regarding Arctic regions has been made available – by the climatologist, the oceanographer, the ice forecaster and analyst, and those who command and operate ships in high latitudes. It is now more than ever impossible to provide a comprehensive review of all Arctic knowledge within the confines of a single manual. This publication has concentrated on highlighting those areas which are likely to be of interest and concern during Arctic naval operations.

Of prime interest are the factors which govern the accessibility of the Arctic Ocean and its peripheral seas, to ships. Considerable emphasis has therefore been placed, in the early chapters of this manual, on the subjects of climate, oceanography and ice, with particular reference to their interrelationship. This constitutes an area of vital concern to the Arctic sailor and the planner of Arctic operations.

The commanding officer or planner is urged to bear in mind the necessity of seeking out and studying those publications which deal with his area of operations. An excellent detailed source for further study of Arctic environmental subjects is the *Arctic Bibliography, Vols I to XIV*, which is available in any Arctic library.

The succeeding chapters of this manual deal with the various facets of Arctic Naval operations. The information contained therein has been compiled from experience gained in a variety of recent northern endeavours.

As this manual goes to press, a super-tanker of over 100,000 tons, specially designed and equipped for an Arctic voyage and supported by icebreakers, is pioneering a commercial route for the bulk transportation of oil through the legendary Northwest Passage, in latitude 75° north. The Arctic seas no longer present a formidable barrier to surface or sub-surface vessels, and, as further specialized environmental and operational knowledge is gained, these ice-covered waters could well become commercial seaways. It seems essential, therefore, that Naval authorities be thoroughly familiar with all aspects of Arctic seaborne operations.



CHAPTER 1

THE ARCTIC ENVIRONMENT

101. GENERAL DESCRIPTION

a. A single expression can often have different meanings, which limits its effectiveness for purposes of definition. "The Arctic" is a term which is sometimes used to indicate the terrestrial basin which is filled by the Arctic or Polar Ocean. For the purposes of this manual, however, "Arctic" must be taken to include the seas contiguous to the Arctic Ocean, the shores surrounding these seas, and in some cases the navigable rivers which flow into these seas and the Arctic Ocean. The criteria commonly used for defining the Arctic regions are discussed below.

b. The word Arctic is a derivation of the Greek work "Bear", which connotes that area lying under the "Big Dipper". Astronomically it is the whole area lying north of 66° 33'N (the Arctic Circle). If this definition is used, some areas of temperate climate are included and some areas of very intemperate climate excluded. However, since this manual deals with the seas and the shorelines for only a very limited distance inland, for all intents and purposes the Arctic Circle could very well be the boundary of the mariner's north. But since such a boundary covers both the true (cold) Arctic and the temperate Arctic, further definitions are called for which will require an understanding of some of the terminology used by scientists.

c. Some scientists have suggested that the boundary of the Arctic be defined northward of the isotherm in which the average temperature of the warmest month is below 50°F (10°C). This closely coincides with the tree-line. The U.S. Army's definition, accepted by the quadripartite countries, is: that portion of the northern hemisphere characterized by having an average temperature of less than 32°F (0°C) and average temperature of the warmest month of less than 50°F (10°C). This roughly coincides with the southern boundary of the zone of discontinuous permafrost.

d. Because it is peculiarly a polar phenomenon, the auroral zone has also been advanced as a criterion for a geophysical definition of the Arctic. The Aurora Borealis, observed in high latitudes as a luminous circumpolar feature, is centred about a point where the geomagnetic pole intersects the earth surface. and its zone of maximum frequency of occurrence can extend south as far as Fort Churchill.

e. Oceanographers consider the Arctic to be that region in which only pure "Arctic water" is found at the surface, at or near 32°F (0°C), and with a salinity of approximately 30°/°°. This water is formed by a combination of:

(1) Water from the Atlantic and Pacific Oceans.
(2) Water drained from surrounding land areas.
(3) Water resulting from the melting of sea ice.

The most important feature is that this water flows out of the Arctic Ocean on the surface, along the east coast of Greenland, through the Arctic Islands, spreading over Foxe Basin and Baffin Bay and is carried as far south as Newfoundland by the Labrador current. Using this as a criterion a line can be drawn north of which all waters may be considered as Arctic waters and which encompasses much of the Sub-Arctic and Arctic, but which again excludes the northern coasts of Norway and the Barents Sea.

f. It can be seen from the above examples that the problem of defining the Arctic boundary is complex. However, for the mariner, the most significant factors to be taken into account are latitude and the extent of the so-called "Arctic waters". For land operations, the line of discontinuous permafrost is the principal boundary to be considered. (See Figure 1-I.)

g. The Arctic has several unique features. The first that comes to mind, of course, is the severe cold of the Arctic winter. Exceptions to this condition have been indicated above, and it should also be noted that over most of the Arctic, and in particular the Arctic Ocean, minimum winter temperatures range between −50°F (−45°C) and −55°F (−48°C), which is comparable to Winnipeg. The coldest temperatures in the northern hemisphere are found not in the Arctic but in the Sub-Arctic latitudes.

h. Generally speaking, throughout most of the Arctic (except in the coastal areas which come under the influence of maritime climatic systems), in Labrador, northern Norway and Kamchatka, precipitation is so low that "desert" conditions might be expected to prevail. However, since much of this light precipitation falls in summer and is prevented from sinking into the ground by permafrost, the surface in summer can usually be found to be wet.

i. Due to the low temperatures, permafrost prevails and this is solely due to the fact that the mean temperature does not rise above 28°F (−2°C). Permafrost is a feature which causes unique engineering problems since any disturbance of the thermal regime leads to the thawing of the permafrost. The high moisture content of the permafrost areas (up to 600 percent or more) causes ground slumping when the soil thaws out, and this is a major factor to be considered when planning construction in the Arctic.

j. The Arctic also has glaciers, but these are not unique to the Arctic since all mountain areas contain some glaciers. Outstanding, of course, is the Greenland Ice Cap. There is no other ice cap of comparable size in the northern hemisphere, but there are many areas (for example east Baffin Island, northern Ellesmere Island and Spitzbergen) where the peaks only rise above the ice of the mountainous areas. The Urals have the fewest glaciers, although there are some in the northern part of the range, and the North Island of Novaya Zemlya is also largely covered by glaciers. Even Iceland has a few small ice caps.

Table 1—I. Arctic Land Environment
(by political units)

	sq. miles	sq. km.
Canada	1,200,000	3,100,000
Greenland	840,000	2,175,000
Iceland	41,000	105,000
Other North Atlantic Islands	24,000	62,000
Continental Scandinavia	7,000	18,000
U.S.A. (Alaska)	210,000	545,000
U.S.S.R.	794,000	2,055,000

k. The one entirely unique feature of the Arctic as previously defined, is the almost complete coverage of the Arctic seas by ice during some part of the year. The main body of the Arctic Ocean is covered year round with pack ice which is continually on the move. It is due to this constant movement of the ice that, even in winter, coverage of the Arctic Ocean is not complete. Ice coverage in winter is about 90 percent, decreasing in the summer to 70 to 80 percent, and in some coastal areas even less. The fringing seas become in summer either ice-free or greatly reduced in ice concentration, with the exception of the northwest part of the Canadian Archipelago where the ice usually remains fast from coast to coast.

l. *Vegetation in the Arctic*

(1) The vegetation of the Arctic falls into two main divisions in the Arctic and Sub-Arctic: tundra and forest. Although the individual plant species involved may vary

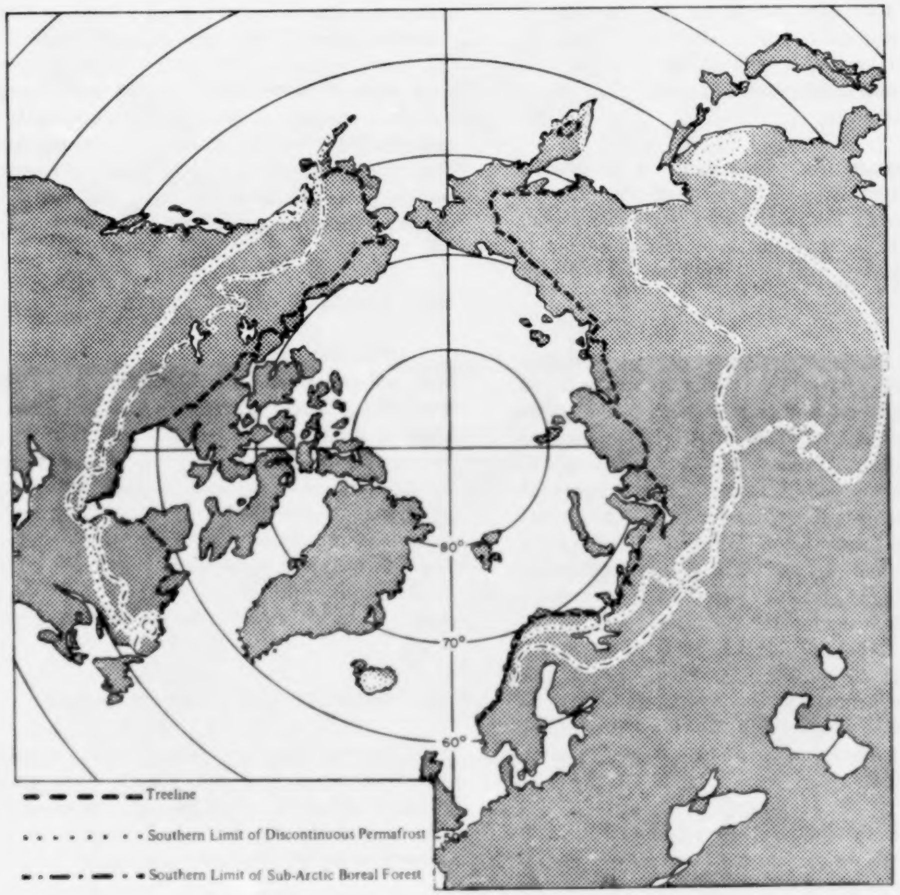

80°
70°
60°
50°
Treeline
Southern Limit of Discontinuous Permafrost
Southern Limit of Sub-Arctic Boreal Forest

Figure 1-1. Boundaries of the Arctic and Sub-Arctic Environments

considerably from area to area, the type and form of vegetation is remarkably uniform and it is this consistent association of vegetation with climate that makes it possible to speak of the Arctic as a single region in spite of all other variations.

(2) The chief characteristic of the tundra is the absence of trees. Tundra comprises creeping shrubs, grass-like plants and mosses. Several zones are recognized, grading from north to south, from almost barren ground to fairly dense growth with small shrubs several feet high.

(3) The forest is the coniferous boreal or taiga, with larch (tamarack) and spruce as the dominant species in the Canadian Arctic and a mixture of birch in the USSR. Generally speaking, the whole forest area is interspersed with low wetlands, known in Canada as "muskeg". By definition, muskeg consists of "more than 6 inches (15 cm) of organic material overlying mineral soils". It may assume several forms such as "perched", "confined", or "continuous" and may include woody material (trees) up to 6 inches (15 cm) in diameter. These trees always develop a tuft at the top and are seldom more than 12 feet (4 m.) in height; therefore muskegs are readily recognizable in the wooded areas. Where muskegs have developed on permafrost, the trees may lean in all directions due to frost heaving. When in this condition they are often referred to as "drunken forests", particularly in the USSR.

m. Generally speaking, in the Arctic, the tropopause (the level at which the fall of temperature with height ceases or reverses sign) is lower than in the tropics. The height of the tropopause varies seasonally in the Arctic from 7 km in February to 10 km in August. There is a sharp separation from the tropical tropopause at about 45°N and this separation is usually the region of the jet stream. The characteristics of the stratosphere above the Arctic tropopause are such that in winter a giant westerly vortex forms around the geographic pole, reaching maximum intensity in February and disappearing rapidly, forming in turn an equally vast but slow-moving easterly vortex in mid-summer. These features of the Arctic tropopause and stratosphere constitute yet another geographical definition of the Arctic, and one which is significant for certain operational requirements.

102. LIMITS OF ARCTIC LANDS

The core of the polar regions is conveniently defined as the lands and seas around the Polar Basin, itself centred roughly on the North Pole. When considering Arctic land areas alone, the southern limits of the Arctic are probably most usefully demarcated by the tree-line. Although this boundary is not ideal, particularly in mountainous areas, it marks a real break between the high winds (and wind-chill) and driving snow of the barren grounds, that are usually underlain by continuous permafrost, and the milder conditions prevailing in the forests to the south. When this definition is in effect, for physiographic purposes three northern countries, Canada, Greenland and the USSR contain nearly 90 percent of the so-called Arctic lands.

103. GEOLOGY AND GEOMORPHOLOGY

a. The major topographical elements of northern lands can only be understood by a brief reference to their geology. The principal geological structures, which have been instrumental in modelling the major elements of the surface of these lands, are arranged in a roughly symmetrical pattern around the polar basin.

b. Three ancient shields formed predominantly of Precambrian

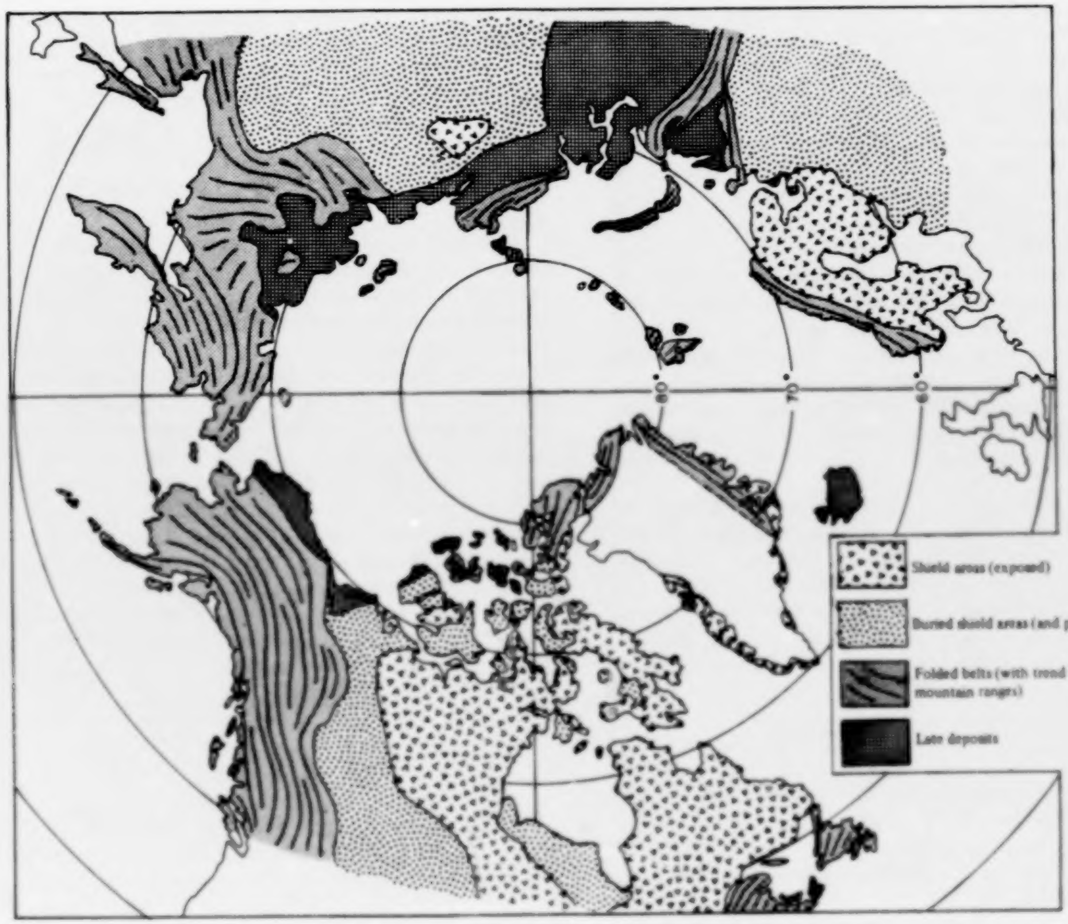

80
70
60
Shield areas (exposed)
Buried shield areas (and platforms)
Folded belts (with trend lines usually mountain ranges)
Late deposits

Figure 1-II. Geological Structure of the Circumpolar World

granites and gneisses are the main structural features of the land surfaces (Figure 1-II). They are the Canadian-Greenland Shield in the western hemisphere, the Scandinavian Shield in northern Europe and the Angara Shield in north-central Siberia. In many sectors the shields extend beyond their exposed margins where they are buried under younger, flat-lying sedimentary rocks. The Angara Shield in particular differs from the other shields in that only a small area is exposed; the remainder being buried under deep sediments. Between the stable shields (and associated platforms) are belts of strongly folded sedimentary rocks which are still evident today, in many areas, as mountain ranges. Where the folding has been unusually intense and is of great age, as in Svalbard and northern Scandinavia, the physiography often differs little from the shield areas. In contrast, the younger fold belts, including those in the northwestern Queen Elizabeth Islands, the mountain ranges of Alaska, and the Kamchatka Peninsula, have developed a scenery that is typically "alpine" in many places. One belt that includes Kamchatka is strongly seismic, comprising numerous active or recently extinct volcanoes.

c. The geology of the bottom of the Polar Basin and adjacent seas remains relatively unknown. The mid-ocean ridge extends northwards from the Atlantic Ocean. A seismic zone, corresponding to the ridge, extends north from Iceland and passes into the Polar Basin west of Svalbard from where it may be traced into the Lena delta. Volcanic activity also occurs along the ridge, notably in Iceland, where it crosses a second oceanic ridge stretching between Greenland and northwest Scotland.

d. The landscapes of the circumpolar regions contain major landforms, the origins of which may be traced to the distant geological past, and minor landforms which have evolved in the last million years. The major elements, particularly the shields, have been elevated and in many cases faulted, and in the coastal areas are deeply dissected by rivers. Today, with some modifications, these uplands dominate the Arctic in eastern Canada, east and west Greenland, Svalbard, Scandinavia and northern Novaya Zemlya. Other widely distributed physiographic areas are geologically younger. Around the north Pacific is a volcanic mountain belt that is part of the zone that encircles the Pacific Ocean; a second, less conspicuous volcanic sector is developed on the mid-Atlantic ridge which crosses Iceland. Regions of very recent sedimentary deposition include the coastal plains of northern Alaska adjacent to the Beaufort Sea, the deltas of the Mackenzie, Yukon and Siberian rivers, and the west Siberian Lowlands.

e. Superimposed on the above are modifications caused by glaciation. Not all the circumpolar lands were glacierized, as aridity was so intense in some areas that glacier ice failed to accumulate. However, all lands around the northern Atlantic, Norwegian and Barents Seas were at some period covered with ice sheets. In the western Arctic, the Yukon and eastern Siberia there are extensive unglaciated areas. The most conspicuous modification by the glacier ice was near the sea where the great outlet glaciers poured down the deep river valleys to the ocean, resulting in the formation of the U-shaped fiords that are such a striking feature of glaciated coastal regions. Channelled ice also excavated deep valleys on the continental shelves, such as the Amundsen Gulf sea valley, and the troughs between many of the Queen Elizabeth Islands and on the Siberian shelf. At the same time, the highest uplands near the sea began to develop alpine scenery with pyramidal mountains, vertically-sided valleys and knife-edge mountain ridges. These are typically found on the west coast of Vest-Spitsbergen. Narrow zones of similar topography are found at many places in northern Scandinavia, Greenland and the eastern Canadian Arctic. By contrast, in the interior of the northern parts of the continents glacierization led to a reduction in relief, either by ice scouring or by redeposition of glacial debris.

f. The latest geological period, sometimes called the "Quaternary", was also a period of major fluctuations in sea level. These included world-wide long-term fluctuations and changes due to reduction of sea level following the growth of the continental ice sheets; and more local changes due to depression of the crust by the weight of

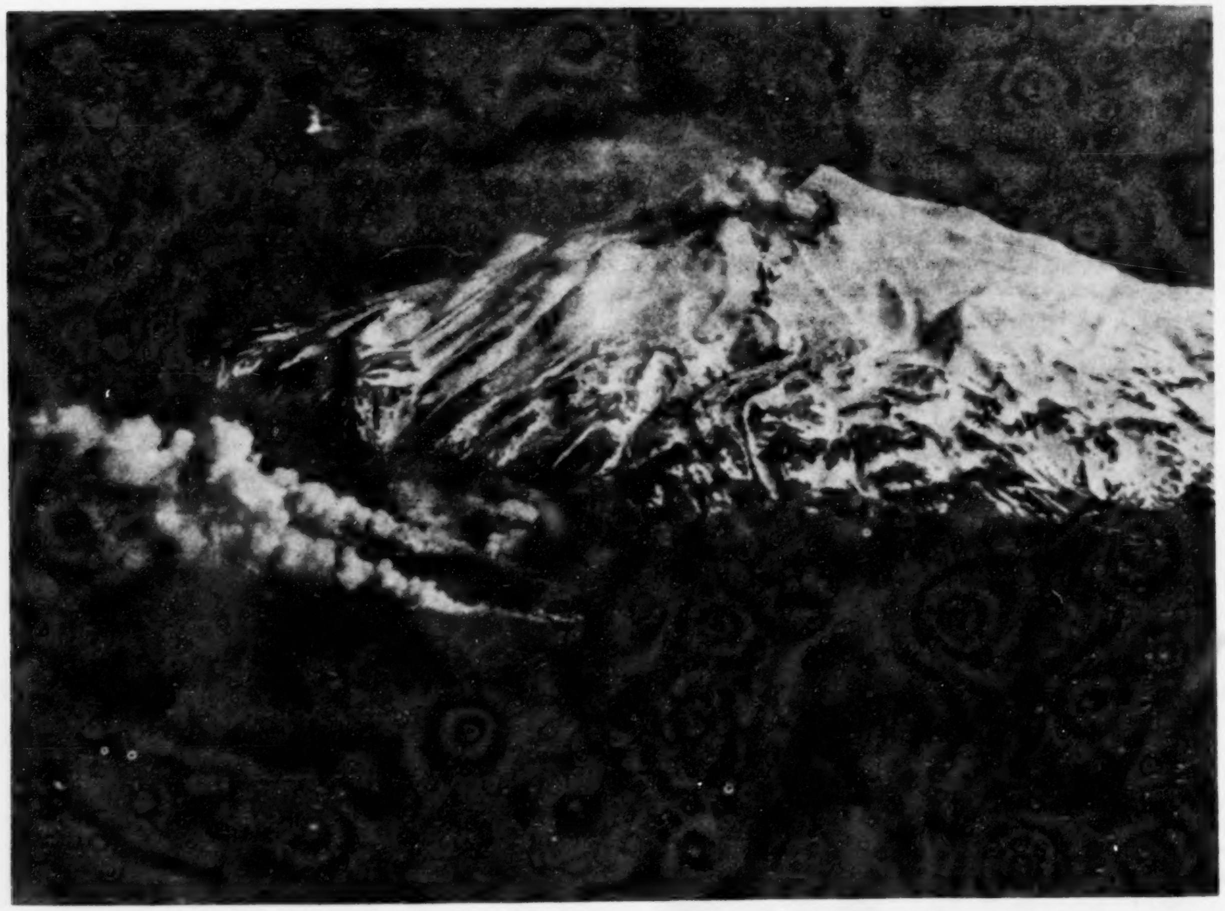


Figure 1-III. Mt. Kiska – An Active Volcano in the Aleutian Island Chain

glaciers. During this period the sea level dropped in those northern areas that escaped glacierization, and at that time the continental shelf off northeast Siberia and northern Alaska probably was land. There is also clear evidence that the interior seas of Arctic Canada were uncovered, as were the channels of Arctic Canada, although in the latter case probably prior to the glacial period. At the close of the period, sea levels in the Arctic were usually higher than today, but around Hudson Bay, in the Arctic Islands and in the northern Gulf of Bothnia uplift due to crustal rebound has exceeded 650 ft. (200 m.). Tide gauge and historical data indicate this emergence is still continuing and reaches as much as 2 ft. (0.6 m.) per century at Churchill, Manitoba and 3 ft. (1.0 m.) per century in northern Sweden.

g. Since the last glaciation, which ended 12,000 to 6,000 years ago, processes unique to the Arctic have produced further changes. These have been caused by low temperatures, the freeze-thaw cycle, the survival of ice in the ground, and the absence of a continuous vegetation cover.

104. THE PHYSIOGRAPHIC ELEMENTS OF NORTH AMERICA, EURASIA AND THE NORTH ATLANTIC ISLANDS

a. Several physiographically distinct areas are recognized in the North American northlands. The largest is the Precambrian Canadian-Greenland Shield that occupies the Canadian Arctic mainland, most of the islands south of Parry Channel and a large part of Greenland. Across this vast area, nearly 2,200 miles in diameter, crystalline granites and gneisses are the dominant rocks. Except where ice buries the land, the scenery is characteristically rocky and rolling with innumerable lakes and ungraded, fast-flowing streams. In North America, superficially the Shield resembles a saucer. It is highest along the eastern margin from Ellesmere Island to northern Labrador where glaciated peaks reach 6,000 to 7,000 ft. (1,800 to 2,150 m.) above sea level, and fiords penetrate inland from the coast. West of the highlands there is a broad upland zone, commonly between 1,000 to 2,000 ft. (300 to 600 m.) above sea level. Within the Shield are basins that are floored by younger rocks, mainly limestones. These have now been partly submerged to form Foxe Basin, Hudson Bay and the channels of the southern part of the Canadian Arctic Archipelago. The western margin is generally less elevated although it produces a conspicuous scarp where it overlooks the Mackenzie Lowland. A belt of plains and low plateaux, including the Mackenzie Lowland and the plains south of the Parry Channel, surrounds the Shield. (See Figure 1-IV.) These lowlands are developed on late sedimentary rocks. The Greenland sector of the Shield also resembles an elongated saucer with a high mountainous rim. The

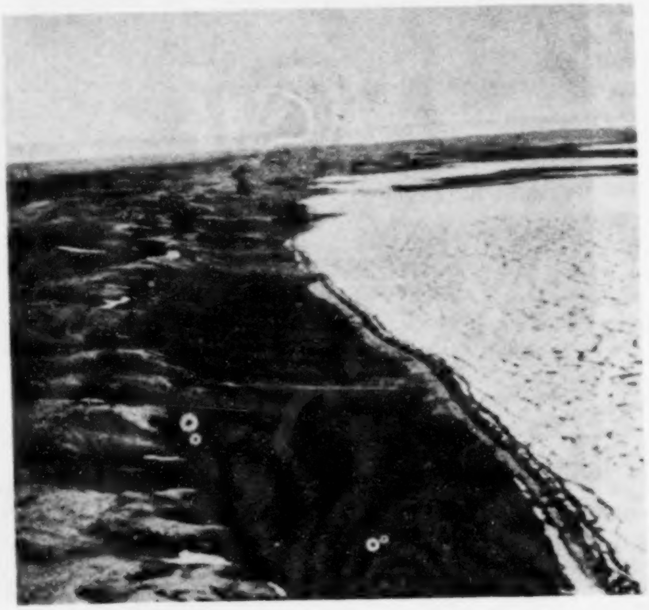


Figure 1-IV. Coastal Plain, Western Banks Island

Canadian-Greenland Shield is partly surrounded by folded rocks of which three main areas can be recognized.

(1) The first and largest is the northern Cordillera of the Yukon and Alaska, which may be divided into three areas: adjacent to the Pacific Ocean is the Pacific mountain system that includes the Aleutian Ranges, and the Alaskan Range; on the north and eastern side of the Cordillera is the Brooks Range of northern Alaska; and there is the Richardson Range of the Yukon and Mackenzie district.

(2) The second folded rock area is in the Queen Elizabeth Islands and includes Melville, Bathurst and Cornwallis Islands, Ellesmere, Axel Heiberg, and Peary Land (Greenland).

(3) The third folded area forms the mountains of northeast Greenland.

b. The Eurasian northlands contain two large shield areas separated by wide depressions. The Scandinavian Shield includes the Kola Peninsula (Poluostrov Kol'skiy) and the northern periphery of Scandinavia. It is an undulating upland with an average elevation of 1,500 ft. (450 m.) and in many ways looks like the Canadian Shield. The surface of the Scandinavian Shield declines in the vicinity of the White Sea, and east of Arkhangel'sk the Precambrian rocks disappear beneath sediments. Along the west side of this shield the Precambrian rocks are replaced by younger, highly folded rocks and there is a deeply dissected highland zone with numerous fiords and alpine peaks exceeding 6,000 ft. (1,800 m.). The second shield area, the Central Siberian Shield, differs conspicuously from the Scandinavian Shield. Only a small section is in the Arctic.

c. Between the two Eurasian shields, a belt of folded rocks along the Ural-Novaya Zemlya axis produces a broad flat-topped upland with a general height of about 3,000 ft. (900 m.). The northern Urals show little sign of glaciation, but Novaya Zemlya is crossed by glaciated valleys and fiords. A second folded zone on the eastern edge of the Siberian shield is a vast highland region, of complex mountains and plateaux. Many of the ranges are arch-shaped, and two of the largest, the Verkhoyanskiy and Cherskiy ranges, both have peaks over 10,000 ft. (3,000 m.). In general the ranges become lower and more confused in the Chukchi Peninsula (Chukotskiy Poluostrov).

d. The West Siberian Lowlands, over 500 miles (800 km) wide, extend southwards from the Kara Sea between the Urals and the Central Siberian Shield. The lowlands are developed on horizontal sedimentary rocks covered with deep glacial, alluvial and marine deposits. They form a remarkably flat, occasionally terraced, badly drained, plain. The smaller, but in other ways similar, North Siberian Lowland area separates the hill ridges of Taymyr' Peninsula from the Central Siberian Uplands to the south. The eastern limit of these lowlands is the mouth of the Khatanga River, but similar plains occur discontinuously far east along the coast and include the New Siberian Islands.

e. Several islands are found in the North Atlantic Ocean and the Norwegian Sea. All have links with the adjacent continents although they are usually treated separately. The largest island, Iceland, is wholly of volcanic origin and lies at the intersection of the Greenland – northwest Scotland and the mid-Atlantic ridges. Three hundred miles (500 km) to the north-northeast is the small volcanic island of Jan Mayen. Farther north still is the island group of Svalbard. The topography has evolved primarily on folded rocks, and is typically mountainous in the west and generally plateau-like and often ice-covered in the centre and east. Everywhere the uplands have been deeply dissected and the lower valleys drowned to produce fiords. (Figure 1-V.)

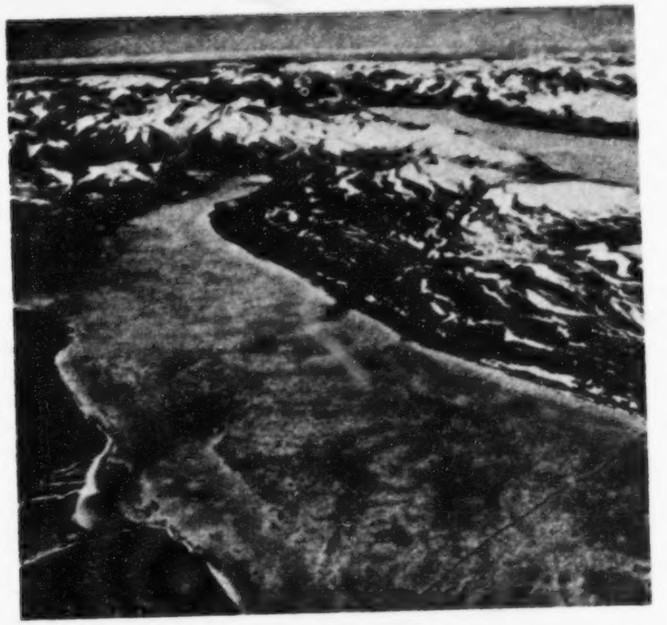


Figure 1-V. Eglinton Fiord, and Sam Ford Fiord, Baffin Island (An example of fiord and alpine geomorphology)

105. PERMAFROST AND TERRAIN

a. Mean annual air temperatures below 28°F (−2°C) lead to sub-soil temperatures that are permanently below freezing point. If the ground beneath the annual surface thawing zone, known as the active layer, remains below freezing point for more than two years, permafrost conditions are said to prevail. Permafrost has an important influence on Arctic soils, landforms and vegetation, and affects the whole pattern of life in northern areas.

b. Where mean annual air temperatures below 28°F (−2°C) prevail, permanently frozen ground is found everywhere except beneath the largest lakes and rivers. In general, above the tree-line, permafrost is continuous except in certain coastal areas. Continuous permafrost is therefore a phenomenon primarily of continental Arctic areas. Where winter temperatures in the Arctic average about 28°F (−2°C), as they do in the Aleutians, Iceland, coastal south Greenland and northern Scandinavia, and in the sub-Arctic forests, areas of permafrost are separated by unfrozen ground and the permafrost is said then to be discontinuous. This zone extends farthest south in the eastern interior of continents and approaches the Gulf of St. Lawrence in eastern Quebec and northern Korea in East Asia. In Arctic continental areas permafrost is commonly from 1,000 – 1,500 ft. (300 – 500 m.) deep. Rather greater depths of up to 2,000 ft. (600 m.) have been found in the northern USSR and there is some evidence that permafrost may be up to 5,000 ft. (1,500 m.) deep in a few Siberian areas.

c. From an engineering point of view the critical part of the permafrost is the active layer close to the surface where freezing and thawing occurs. It varies considerably in thickness and is dependent on site, exposure, soil drainage and vegetation. In the high Arctic at poorly-drained sites, the active layer may be less than 4 in. (10 cm), whereas near the southern margins of permafrost, in favourable localities, it may be 6 to 10 ft. (2 to 3 m.) thick at the end of the summer. The maximum depth of the active layer under most favourable conditions may be in excess of 13 ft. (4 m.). The chief significance of this layer is that moisture content is often abnormally high, which creates serious problems for construction engineers and also, in some cases, completely inhibits summer ground mobility.

d. Many other landforms are found only in northern areas. One striking feature in these areas is the vast quantity of shattered bedrock lying on the surface and covering the valley sides. This broken bedrock results from frost shattering.

e. The presence of ground ice leads also to unusual landforms. Ground ice exists in most areas where there is permafrost, occurring as ice in the soil pores, and as veins, wedges and sheets. The most spectacular ground ice occurs on the coasts of central and eastern Arctic Siberia where massive occurrences of ice, up to 230 ft. in thickness, have been reported. Elsewhere in the Arctic, particularly in the presence of silts, and especially in deltaic areas, ice mounds may develop covered either by organic or mineral soils. These mounds vary in height from a few centimetres to more than 165 ft. (50 m.), and are known as "pingos". They are generally found in the Siberian river deltas, the Mackenzie delta, and the coastal plains of northern Alaska and Siberia.

f. If a change in the environment takes place resulting in the melting of the ground ice, hollows with uneven topography known as "thermokarst" form. Tundra ponds also develop when ground ice melts.

g. A conspicuous feature of the terrain in Arctic areas is the tendency for soils to develop regular textural patterns. The term "patterned ground" includes all such features that occur in vegetation and soils, on horizontal and on sloping ground. It is caused primarily by a complex process of sorting of the materials comprising the soil, due to the freeze-thaw cycle, or by the development of regular hexagonal patterns due to the thermal contraction of the active layer.

h. The surface layers of the soil often become supersaturated with water during the spring and summer, and movement (which may even be perceptible through a period of a few days) may occur on gentle slopes. This phenomenon, known as solifluction, develops throughout the Arctic and results in patterns which are usually called "soil glaciers". In mountainous regions, features known as "rock glaciers" or "rock streams" sometimes occur, in which, instead of soil, boulders are in motion "lubricated" by ground ice or a mixture of soil and ground ice.

i. Heavy snowfall is not common in the Arctic and, indeed, exceptionally heavy snowfalls are restricted to mountainous and maritime areas. However, snow lies for long periods and has an important influence on northern terrains. The killing effect of the wind on vegetation during the winter months is reduced by a snow cover, and in the southern Arctic the height of bushes is commonly controlled by the depth of the snowfall.

106. PERMANENT LAND ICE

a. Less than 5 percent of the Arctic lands are covered with permanent ice. (See Figure 1-VII.) Greenland is the only area where glaciers totally dominate the land, and an ice sheet comparable to the great ice-caps of the glacial periods, 6,000 to 12,000 years ago, survives. The main Greenland ice-cap is nearly 1,500 miles (2,400 km) from north to south and is roughly 700 miles (1,100 km) across at its widest. Beyond the confines of Greenland, the ice sheet has a significant influence on the climate of some of the northern circumpolar lands and is the main source of icebergs in the northern seas. It has been estimated that if all the ice in the Greenland ice sheet melted, the level of the world's oceans would rise by 21 ft. (6.5 m.). Greenland has the shape of an elongated basin surrounded by a mountain rim which is highest and widest along the eastern side. The interior of the rock basin is close to sea level on the average, while nearly a third of its total area (200,000 sq. miles: 500,000 sq. km.) is below sea level. Inland from the coast the first hundred kilometres of ice is often crevassed and, particularly along the east coast, there are "nunataks" where the underlying mountains break through the ice sheet. Further inland the crevasses disappear and the smooth, gentle slopes of the ice-cap prevail. In the interior, the ice sheet reaches over 10,000 ft. (3,000 m.). Great ice streams flow from this source through gaps in the mountain walls to the sea. (See Figure 1-VI.)

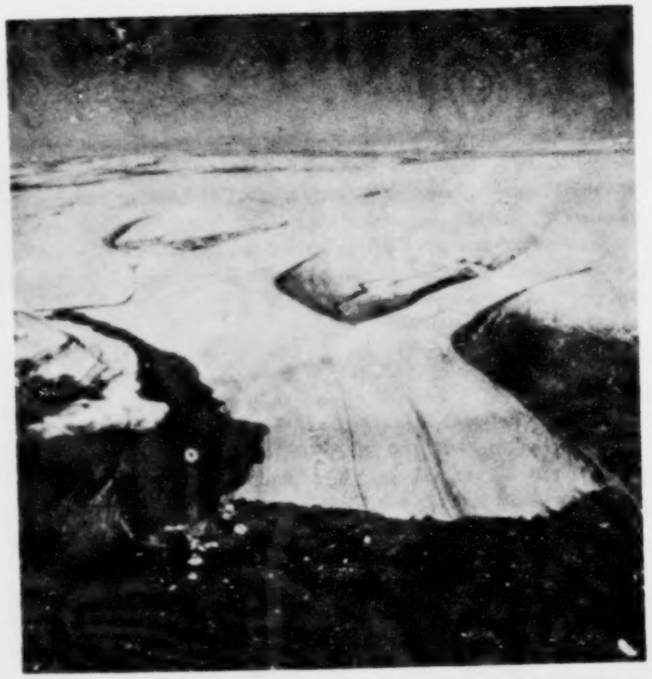


Figure 1-VI. Chamberlain Glacier entering Wolstenholme Fiord (northwest Greenland)

b. The distribution of the remainder of the glaciers in Arctic North America is closely related to topography and moisture supply. In Arctic Canada glaciers occur geographically in three groups. The most southerly group (which are really semi-permanent snowfields) are in the Torngat Mountains of Labrador, where at the present time they are rapidly retreating. Permanent ice is more plentiful north of Hudson Strait, and the most southerly ice-caps occur on the uplands on both sides of Frobisher Bay. Larger ice-caps, often completely submerging the underlying mountains, are found on Baffin Island north of Cumberland Sound, on Bylot Island, East Devon Island, and in three southern sectors of Ellesmere Island.

c. A second group of Canadian glaciers are adjacent to the Arctic Ocean in northern Ellesmere Island and on Axel Heiberg Island. The third group consists of the four small ice-caps on Melville Island. The remaining glaciers of Canada are found in the western mountain ranges and are not strictly Arctic in character.

d. In Alaska there is an important difference between the small number of Arctic glaciers of the Brooks Range and the Romanozov Mountains, and the vast glacier systems on the mountains adjacent to the Pacific Ocean, including the border ranges between Alaska and the Yukon, the Aleutian Range and smaller glaciers of the Alaska Peninsula.

e. Snowfall is not as heavy on the northwestern side of the Pacific Ocean, and glaciers are restricted to the Kamchatka Peninsula.

f. The North Atlantic Ocean and the Norwegian Sea constitute a major source of moisture for Arctic glaciers in Scandinavia. This moisture is carried by the winds as far as north-central Siberia (the Urals), and wherever there is sufficient relief there are small ice-caps. However, the mainland of the Russian Arctic outside the Urals has no permanent ice and neither do the eastern islands of northeastern Siberia, excepting Bennett Island. In Scandinavia, permanent ice is restricted to the highest land, normally in excess of 6,500 ft. (2,000 m.). The altitude of glaciation becomes progressively lower in a northeastward direction, until it is below 1,600 ft. (500 m.) on the Severnaya Zemlya Islands.

g. A large expanse of ice covers Iceland, where the largest glacier is Vatnajökull. The other large glaciers are all in the southeastern or central parts of the island. North of Iceland, Jan Mayen Island supports an ice-cap, but Bear Island farther northeast is much lower and has no

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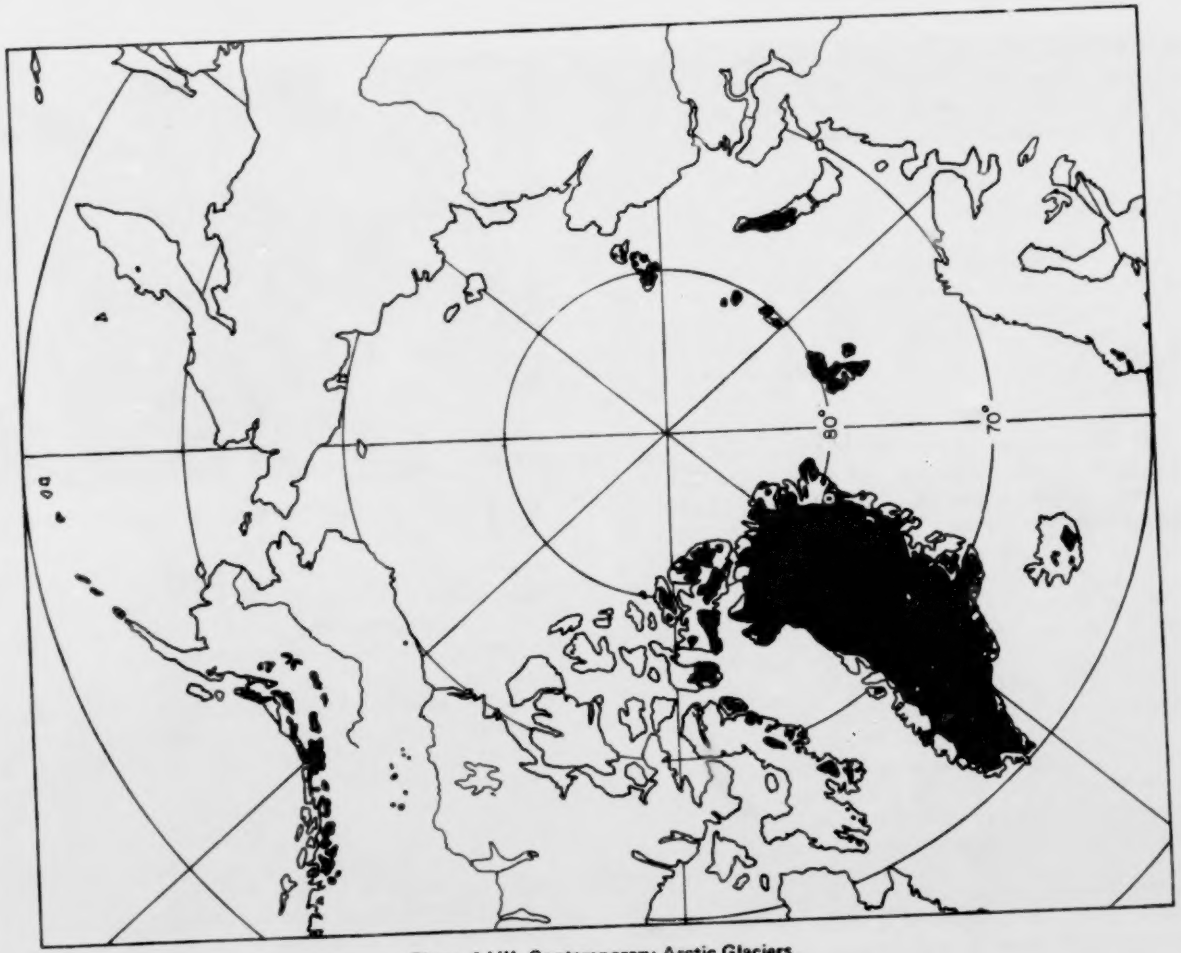


Figure 1-VII. Contemporary Arctic Glaciers
(Shaded areas are glaciated)

permanent ice. There are numerous glaciers in Svalbard and Northeast Land is largely covered with thin plateau ice. Other islands around the Barents Sea, including the northern third of Novaya Zemlya, Franz Josef Land and Severnaya Zemlya all carry large ice-caps.

107. BEACHES AND CLIFFS

a. Arctic littoral processes in ice-free summer months do not differ greatly from those in temperate latitudes. The differences are more of degree than of kind, particularly as the annual period of wave action and the amplitude of the waves is reduced by the presence of ice. However, several distinctive processes are operative at break-up and freeze-up of sea ice.

b. Sea ice has, in general, a secondary role to waves as an agent in erosion, transportation, and deposition. With the onset of winter, when air temperatures drop below freezing, an ice shelf (storm-ice foot or ice rampart) commonly forms along Arctic beaches where there is a low tidal range, as water from storm waves and spray freeze on the beach to leave layers of ice-cemented gravel and ice. Sand and gravel are often washed onto the developing ice shelf and become incorporated. This ice shelf "armour" protects the beach against subsequent wave action and ice-shove. If the pack ice should move onshore early in the winter, shore-fast ice with adhering debris may be shoved inland onto the beach thus adding material to the beach. (See Figure 1-VIII.)

c. During the winter, shore-fast ice and offshore ice stop all wave action. Pack ice at break-up, and also later in the summer, may push onto the beach and even impinge against the sea cliff, if present. Ice moving onto a beach tends to act either as a plough or a raft. Where ploughing occurs, the ice planes and pushes debris into mounds and ridges, usually below the upper limit of storm waves. Where rafting occurs, debris frozen and incorporated in the ice may be transported onto the beach, locally above the reach of storm waves. Usually, storm waves soon rework most of the transported material and by freeze-up, little evidence of it is visible; however, in the high Arctic bays and channels that are permanently choked with ice, ice-push beach ramparts are a normal feature at the rear of beaches.

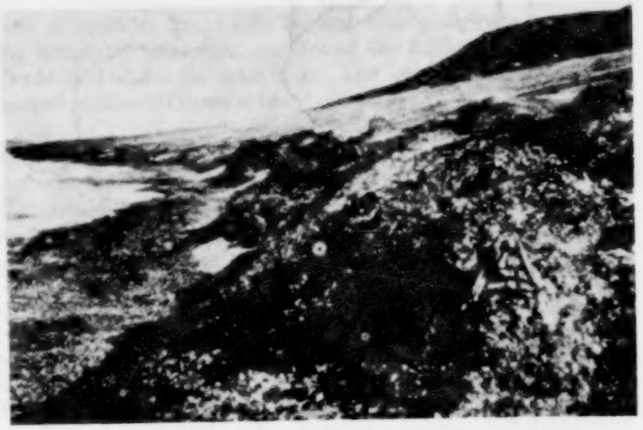


Figure 1-VIII. Ice-shove Ridges, Nansen Sound, Northern Canada

d. On coasts where the tidal range is considerable, boulder barricades are the most conspicuous sign of the action of sea ice. Typically there is a narrow string of boulders parallel to the shore and several hundred feet out. At low tide they are clearly visible above the water surface whereas at high tide they are submerged. They represent a navigational danger on the approach to many open beaches. Generally the depth of water increases rapidly beyond the boulder limit. The pushing and rafting of boulders by the moving sea ice that forms the boulder barricades is also responsible for the development of boulder-covered flats which are exposed at low tide near the heads of Arctic bays.

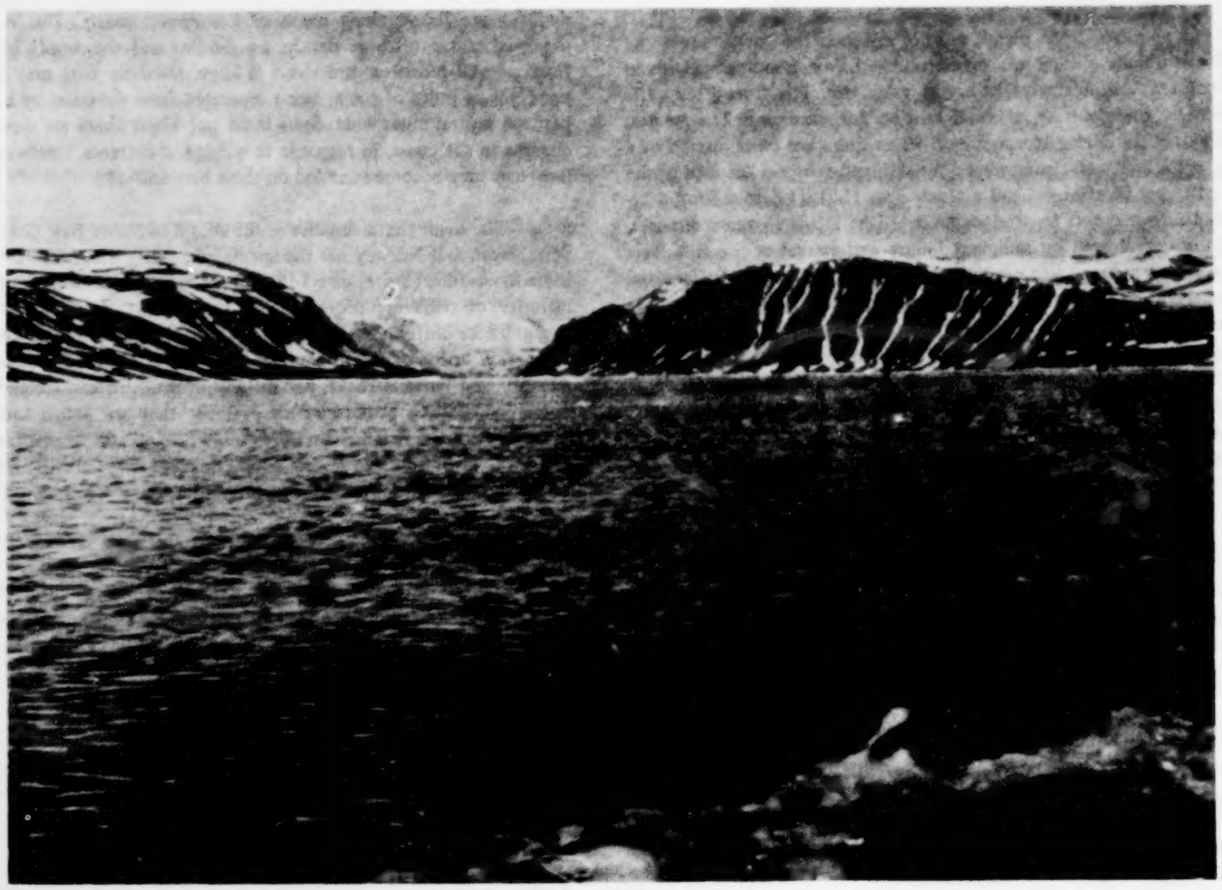


Figure 1-IX. The Labrador Coast

e. Cliffs of unconsolidated materials, which may rise to 100 ft. (30 m.) or more, front many miles of coast in the Pacific area. The cliffs are usually eroded into unconsolidated, frozen sediments with an ice content varying inversely as the grain size. The frozen sea cliffs retreat by undercutting, thermal erosion and slumping. The greatest erosion occurs during storm surges. When there is a combination of a high water level and strong waves, the slumped debris at the foot of the sea cliff may be removed and a notch 5 to 15 ft. (1.5 to 4.5 m.) deep eroded into the cliff to produce an overhang in the frozen sediments, and this is followed by sediment failure and retreat of the cliff face. Thermal erosion may also produce glacier-like mud streams. Differential thermal erosion is particularly marked along coasts where large ice-wedges of tundra polygons are present. Gullies selectively etch out the ice-wedges to produce indentations or hanging valleys along the cliffs. In winter, the sea cliff and beach zone is an accumulation site for large snow-drifts which persist and protect the cliff foot in early summer. Rapid slumping from above may bury the snow-banks completely and some survive over the summer, thus adding additional protection to the cliff foot for a second summer season. The type of sediment in the sea cliff tends to be reflected in the number and size of adjacent beaches and bars. As a generalization, beach and bar formation diminishes directly with reduction of grain size; icy muds may have no associated beach and bar deposits.

f. Offshore bars, bay-mouth bars, spits, tombolos, and other bar deposits are found along much of the Arctic coasts. This is to be expected where offshore depths are modest and the supply of debris from coastal recession and rivers is large. Offshore bars may parallel hundreds of miles of coast, being separated from the coast by a lagoon perhaps several miles wide. Spits build out where there are directional changes in the coast, in response to winds and currents. Driftwood and large logs may become stranded on these bars and spits.

g. The main characteristics of the shores of Baffin Bay, Greenland, Spitzbergen and Norway are the spectacular cliffs which can be found in many sectors. (See Figure 1-IX.) In the Precambrian Shield areas the majority of cliffs are preglacial, or, in the case of fiords, of glacial origin. These cliffs show little evidence of strong contemporary erosion subaerially or by waves. In contrast, many of the cliffs in younger sedimentary and igneous rocks, particularly in Svalbard and Iceland, have developed massive postglacial scree slopes that are active today. In some parts of the Atlantic Arctic, notably Scandinavia, a rock platform that varies in width up to several kilometres separates the cliffs from the sea. This feature, known as the strandflat, may be drowned, thus forming a "skerry coast".

108. DETAILS OF COASTAL TOPOGRAPHY

Detailed descriptions of the Arctic coastline of the areas covered in this manual are contained in the appropriate Sailing Directions.

CHAPTER 2

CLIMATE

201. INTRODUCTION

a. Knowledge of the Arctic climate and weather conditions has reached a fairly satisfactory state. Coastal and island stations have been in operation for a period long enough to give statistical information sufficient for a description of the regional climates. In addition, observing stations on ice islands or on the pack ice itself have, since 1950, contributed greatly to increased understanding of the weather and climate over the Arctic Ocean.

b. Since much of the northern land surface is of low elevation, there is little obstruction to free atmospheric flow between the middle latitudes and the Arctic. The areas of highest relief are Greenland, Ellesmere and Baffin Islands in Canada, the Brooks and Alaska ranges in Alaska and the mountains of Scandinavia. It is, therefore, not to be expected that fundamental differences should exist between the weather processes in middle and in high latitudes. Indeed, few such differences do exist. The special and typical conditions met with in the Arctic are mainly those resulting from:

(1) the distinctive regime of daylight and darkness together with low solar elevation which result in a prolonged period of radiational loss from the surface,

(2) the high reflectivity of the surface as long as snow remains on the ground, and

(3) the low moisture content of the air in winter in many areas of the Arctic, because of the ice cover on lakes and ocean.

c. The wetness, warmth, roughness, relief and albedo (reflectivity) of the earth's surface are among the major determinants of weather and climate. The stability of air changes with the characteristics of the underlying surface, cooling producing a stable stratification and a shallow layer of modified air, while heating from below steepens the temperature lapse rate and causes instability.

d. The roughness, texture, wetness and colour of the Arctic landscape change little within each of the two seasons but vary markedly from summer to winter and vice versa. The generally ice-covered Arctic Ocean is probably the most important of these surfaces, because of size alone (5.4 million sq. miles: 14 million sq. km.), but the Greenland Inland Ice and the tundra lands of North America and Eurasia are also regions of active air mass modification in both seasons. Finally, smaller areas of permanent ice and snow cover exercise local influences. There are roughly 20,000 sq. miles (52,000 sq. km.) of glaciers and ice-caps in the USSR, 50,000 sq. miles (130,000 sq. km.) in northern Canada, and 22,000 sq. miles (57,000 sq. km.) in the Svalbard Archipelago.

e. The extension of polar sea ice is smallest in September, when it covers approximately three million sq. miles (7.8 million sq. km.), and greatest in March (approximately six million sq. miles: 15.6 million sq. km., or nearly 11% of the sea area of the northern hemisphere). The neighbouring seas are also frozen in March. Hudson Bay and Hudson Strait add nearly half a million sq. miles (1.3 million sq. km.) to the ice-covered surface in winter, and the Bering Sea, Sea of Okhotsk, White Sea and the Gulfs of Bothnia, Finland and St. Lawrence form southern fringe areas of a snow and ice-covered polar cap. Thus the polar cap extends south of 60°N everywhere except in the North Atlantic region,

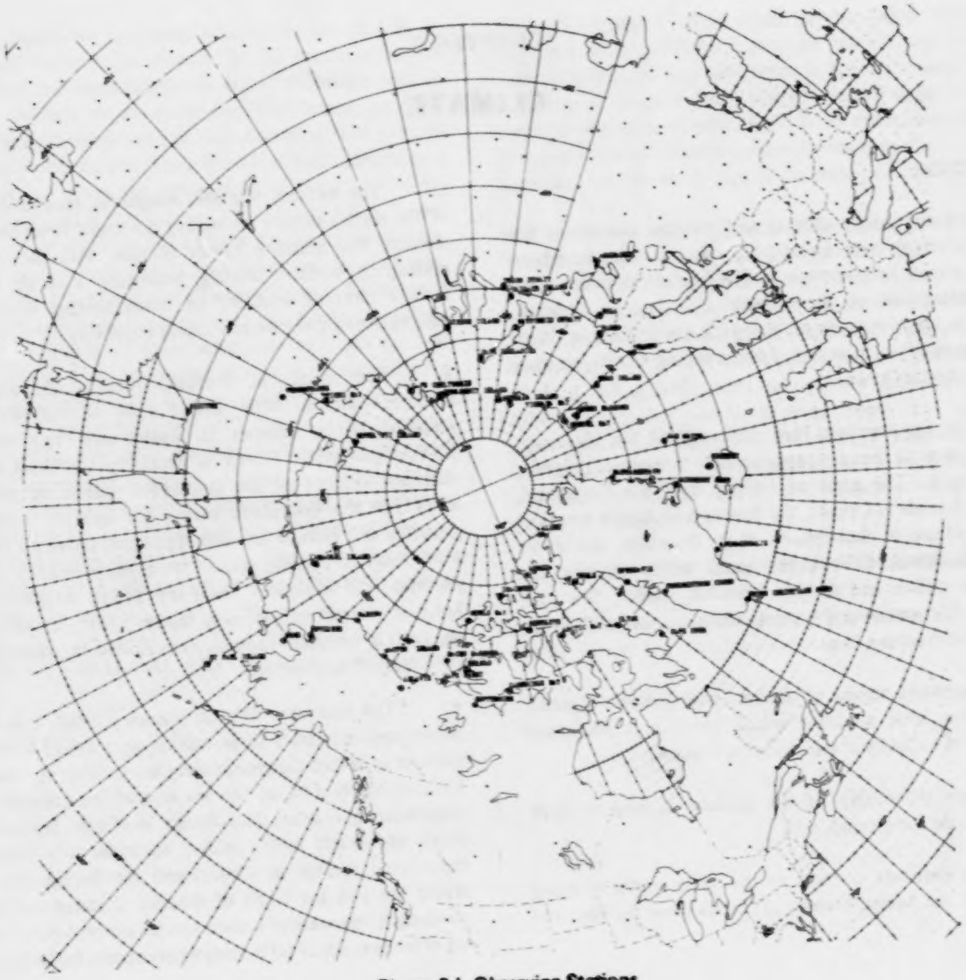


Figure 2-1. Observing Stations

Table 2-I. Observing Station Locations
(See Figure 2-I)

Station	Latitude	Longitude	Elevation (feet)
Green Harbour	7802N	1415E	36
Mossel Bay	7954N	1627E	–
Tromso	6939N	1857E	335
Bear Island	7428N	1917E	133
Vardo	7022N	3106E	39
Kola	6853N	3301E	23
Archangel	6428N	4031E	20
Tikhaya Bay	8019N	5248E	20
Matochkin Strait	7316N	5624E	59
Rudolfa Island	8148N	5757E	157
Vaigach Island	7024N	5848E	36
Yugor Strait	6949N	6046E	43
Cape Zhelaniya	7657N	6834E	26
Dikson Island	7330N	8024E	66
Domashniy Island	7930N	9108E	10
Cape Chelyuskin	7743N	10417E	16
Tiksi Bay	7135N	12856E	33
Verkhoyansk	6735N	13330E	400
Kotel'nyi Island	7602N	13806E	11
Cape Shalaurova	7311N	14314E	26
Okhotsk	5921N	14317E	16
Wrangel Island	7058N	17833W	10
St Paul Island	5709N	17013W	22
Nome	6430N	16526W	46
Kotzebue	6652N	16238W	16
Barrow	7118N	15647W	13
Barter Island	7008N	14338W	39
Aklavik	6814N	13500W	30
Sachs Harbour	7157N	12444W	277
Cape Parry	7010N	12441W	53
Mould Bay	7614N	11920W	50
Holman	7030N	11738W	30
Coppermine	6749N	11505W	28
Cambridge Bay	6907N	10501W	47
Isachsen	7847N	10332W	83
Resolute	7443N	9459W	209
Eureka	8000N	8556W	8
Arctic Bay	7300N	8518W	36
Thule	7634N	6848W	129
Clyde	7027N	6833W	10
Alert	8230N	6220W	205
Cape Dyer	6635N	6137W	1207
Upernavik	7247N	5609W	210
Sondrestrom Fjord	6700N	5048W	190
Prins Christians Sund	6003N	4312W	250
Angmagssalik	6530N	3733W	95
Scoresby Sund	7028N	2158W	56
Danmarkshavn	7646N	1845W	20
Grimsey	6630N	1801W	72
Jan Mayen	7059N	0820W	76

and in the Norwegian and Barents Seas where Atlantic water enters the Polar Basin and submerges to form the intermediate layer of Atlantic water in the Arctic Ocean.

202. AIR PRESSURE

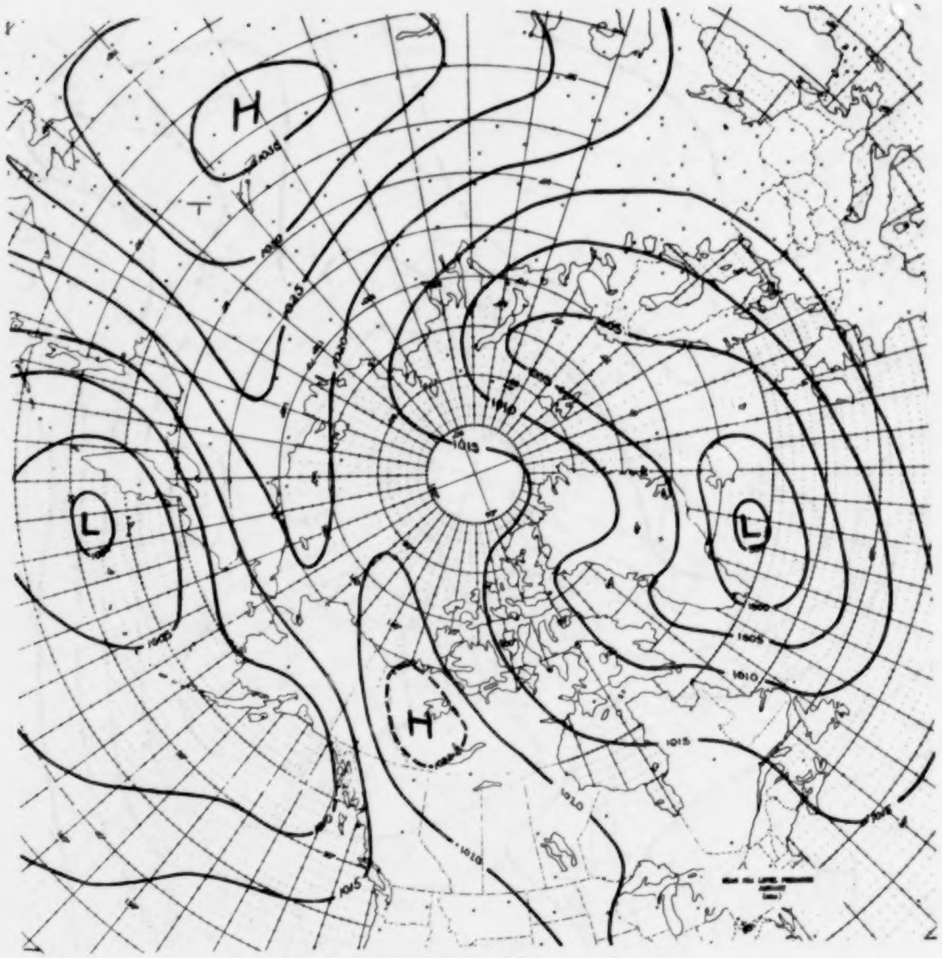
a. *Winter.* The distribution of mean sea level pressure for January (Fig. 2-II) summarizes the winter situation. The circulation is dominated by four large cells, two continental highs and two oceanic lows. The large, semi-permanent Siberian high is joined to a smaller high over the Mackenzie Valley (1,023 mb.) by an elongated ridge across the Arctic Ocean. The Icelandic low (994 mb.) controls the mean circulation along and over northern Scandinavia and the sea areas on the Eurasian side of the Pole. An elongated trough follows the open water and runs from Iceland north of Norway to Novaya Zemlya and the Chelyuskin Peninsula. Another trough covers Baffin Bay. Both troughs are actually the scene of frequent cyclonic activity. The remaining cell is the smaller Aleutian low. The circulation over the Pole itself is largely dominated by the cyclonic flow around the Icelandic low. There is no "Arctic High" on the January mean map, as stipulated by older theories for the Arctic Ocean, although strong anticyclones are common over the Basin. The "Polar easterlies" exist, in winter, in the mean flow only over the Norwegian-Barents Sea area and along the north flank of the Aleutian low. Because of the extreme asymmetry and eccentricity of the sea level pressure field, no single latitude circle shows any appreciable integrated easterly flow. Over the central Arctic Ocean, the main air stream in January is directed from the middle and western Siberian coast towards the Pole and thence, southward across the Greenland-Svalbard area. On the Bering Strait side of the Pole the Siberian air masses cross the Polar Ocean and invade the Canadian Archipelago, mixing with air from the Alaskan-Yukon area. Over the regions of elevated topography the pressure gradients are fictitious, as for example over Greenland, where the surface winds are not accurately depicted by the pressure map.

b. *Spring and Summer.* The January pattern generally persists into March. Thereafter the mean pressure field undergoes rapid change. There is pronounced weakening of the low cells and of the Siberian continental high, and a relative intensification of high pressure over the Arctic Ocean. It is in the spring that strong anticyclonic activity is most likely to occur over the central Arctic, and it is at this time that the concept of a "Polar Anticyclone" is most nearly fulfilled. In summer (Fig. 2-III), the mean pressure gradient over the central Arctic Ocean is relatively weak. A closed anticyclone is found over the edge of the Arctic Ocean covering the Barents Sea (1,013 mb.), while a weak ridge is located over the Beaufort Sea (1,013 mb.). The Aleutian low diminishes to a feeble trough in summer, and the Icelandic low is also weak (1,010 mb.). The Siberain high disappears completely and is replaced by a thermal low pressure area over the heated Asiatic land mass. The July mean pressure map thus shows a feeble pattern with a sluggish resultant mean flow. The prevailing air currents over the Eurasian coast are directed from the Arctic Basin to the coast, with a marked easterly component, so that on the Siberian coast the winds are generally ENE, while on the coast westward of 90°E the prevailing wind is from the NE.

c. *Autumn.* By October the pressure patterns show a superficial resemblance to the spring conditions. Relatively high pressure occurs over the central Arctic Ocean and the sub-Polar lows are back in their customary positions. The mean pattern, however, represents a compromise between contrasts of vigorous cyclonic circulation systems and periods of anticyclonic control. The Aleutian low regains its full intensity and the Icelandic low approaches wintertime strength, the extension over Novaya Zemlya being re-established. The Siberian high attains moderate intensity in October (1,018 mb.).

203. PRINCIPAL TRACKS OF CYCLONES AND SYNOPTIC SYSTEMS

a. Figs. 2-IV and 2-V supplement the charts of mean pressure by


H
L
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1005
1010
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1020
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1015

Figure 2-11. Mean Sea Level Pressure – January

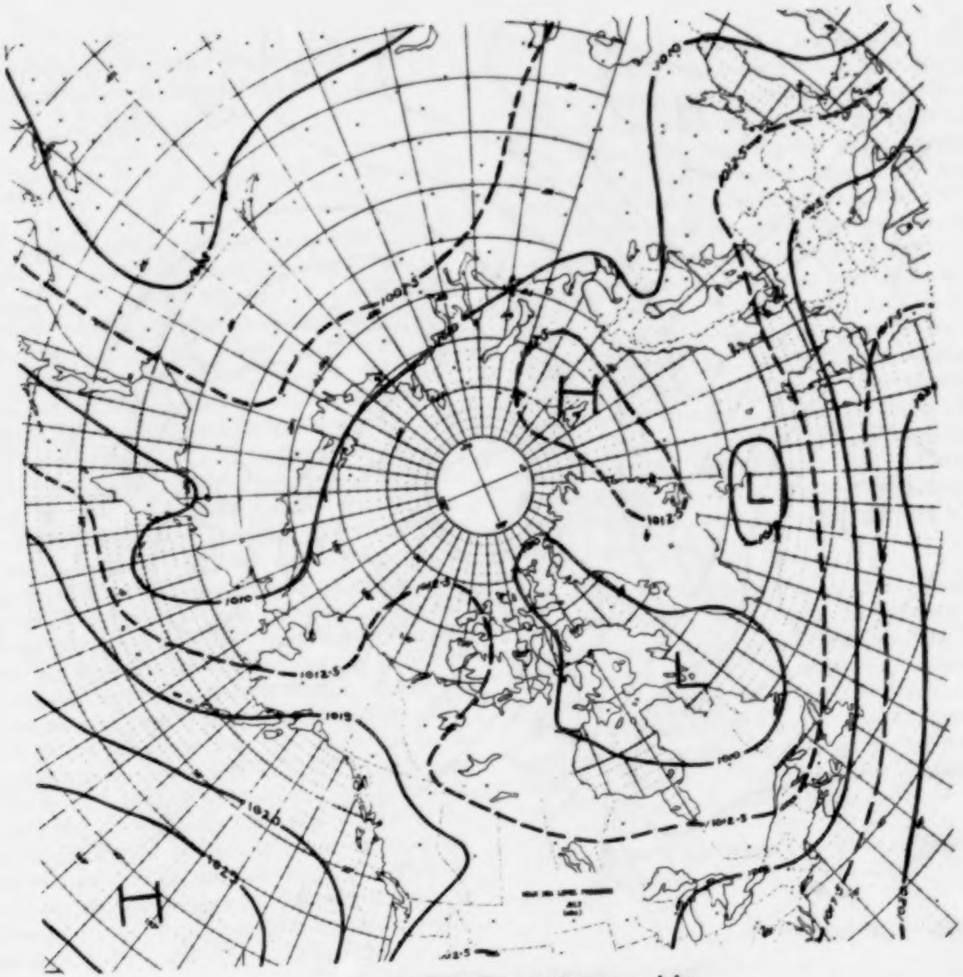
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Figure 2-III. Mean Sea Level Pressure — July

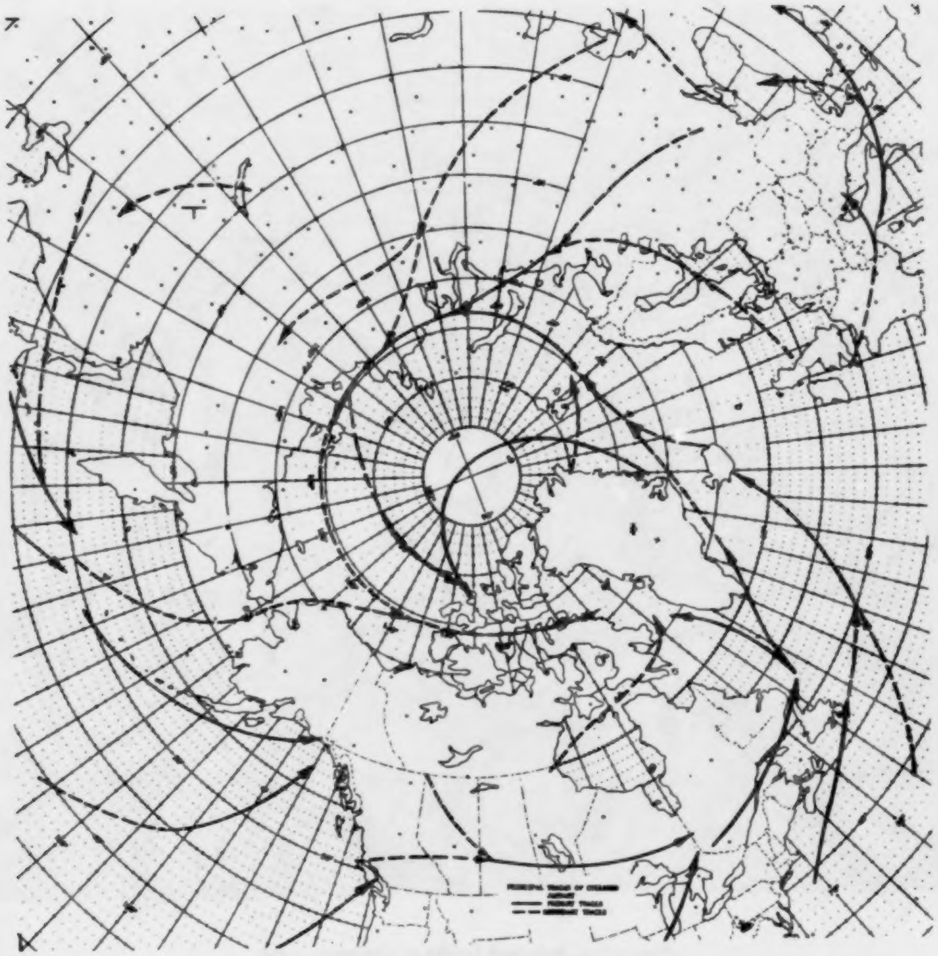


Figure 2-IV. Principal Tracks of Cyclones — January

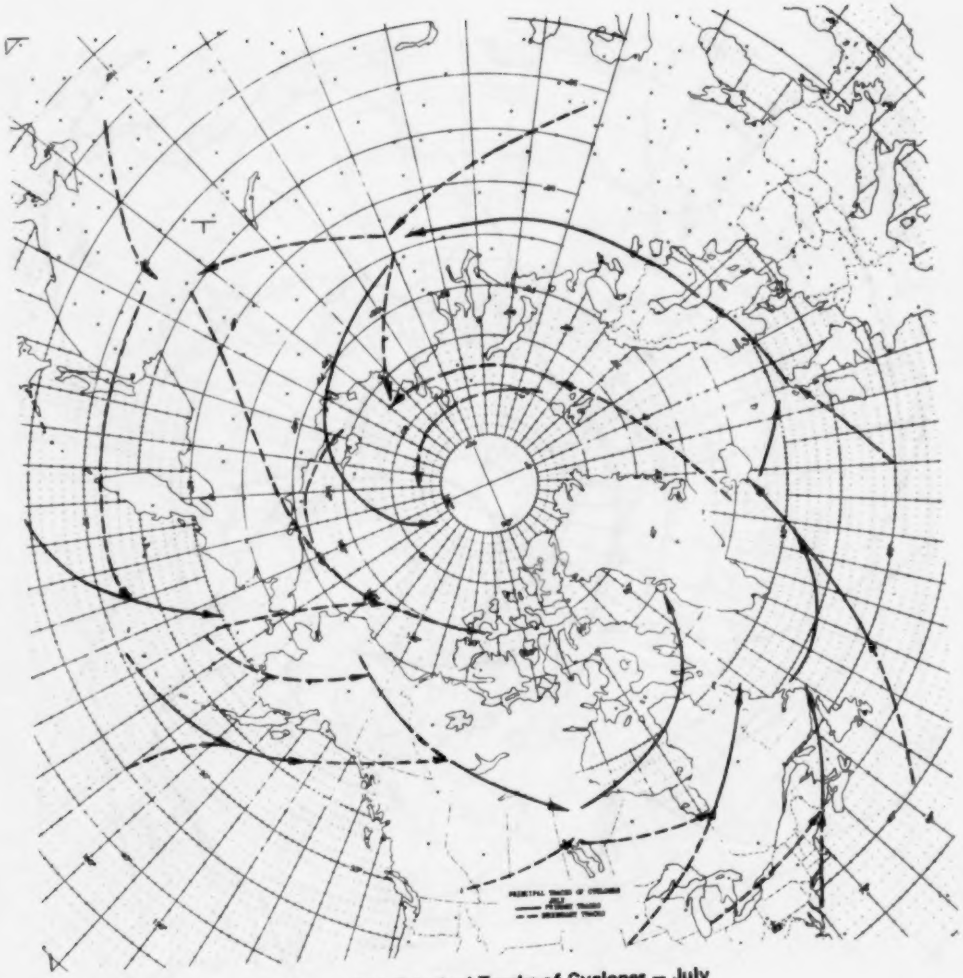
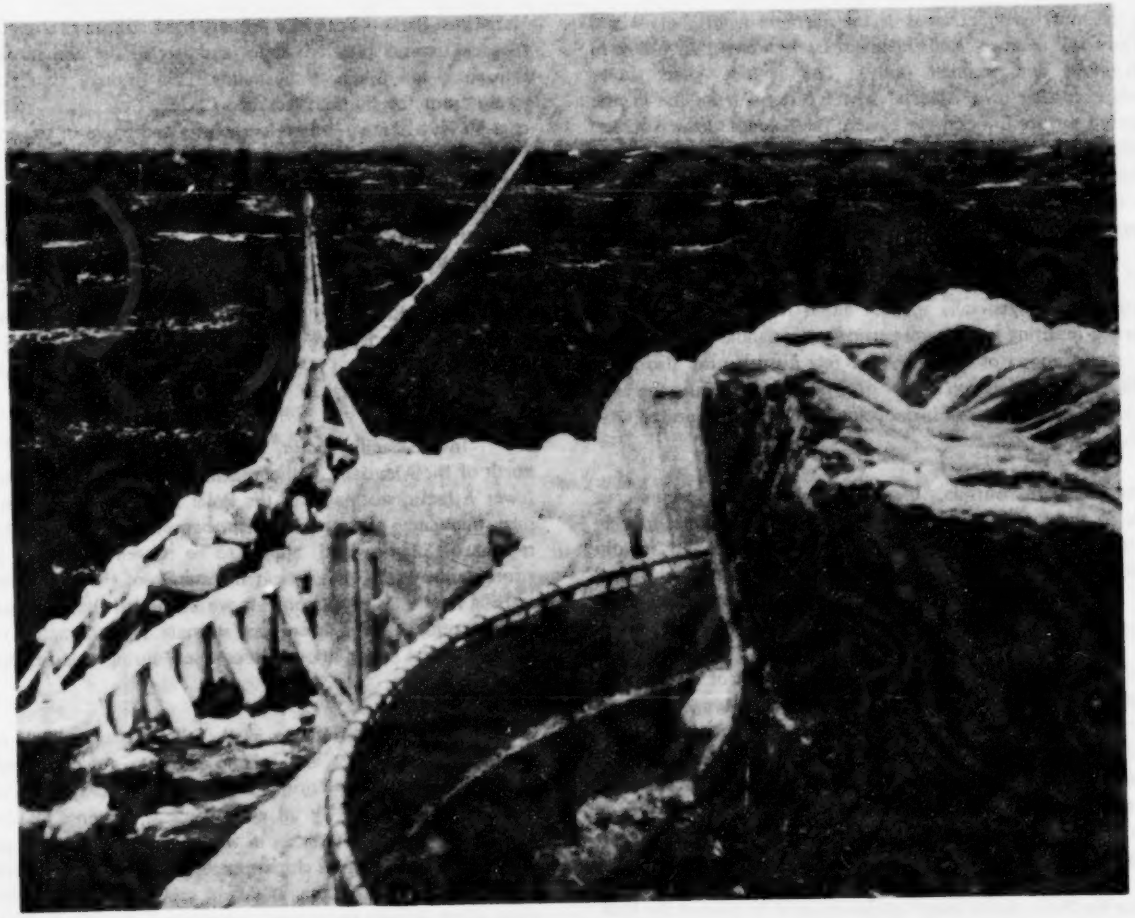

PRINCIPAL TRACKS OF CYCLONES
JULY
PRIMARY TRACKS
SECONDARY TRACKS

Figure 2-V. Principal Tracks of Cyclones — July



indicating the most frequent areas of the northern hemisphere where cyclones form and dissipate, and the major tracks which they follow in winter (January) and summer (July). The January chart shows cyclogenesis occurring over Alberta, where systems from the Pacific produce closed surface lows on the eastern (lee) slopes of the Rockies. These cyclones generally move east-southeastward, converging with tracks from the southwest and south to a centre of maximum frequency over the Great Lakes. Most of these disturbances are then steered northeast to Newfoundland. Here they are joined by cyclones from the east coast, where thermal contrasts between the cold continental and warmer maritime air favour cyclogenesis. From Newfoundland storms generally migrate either towards Iceland (their high frequency resulting in the semi-permanent Icelandic low), or along the west or east coasts of Greenland. A few disturbances also enter Davis Strait by way of Hudson Bay or drift in erratically from the west Canadian Arctic, and an area of high cyclonic frequency is located west of Greenland.

b. Over northern Eurasia, there is no cyclonic development comparable to that over continental North America. Cyclones moving eastward into Siberia are often old occluded storms and rapidly decrease in intensity, although secondary cyclones occasionally form near Lake Baikal and deepen rapidly on moving towards the Pacific coast.

c. Surface low centres moving southeastward out of Siberia may cause outbreaks of intensely cold air over China and Mongolia. These are associated with strong cyclogenesis off the east Asian coast. The majority of these east coast storms are steered northeastward toward the Aleutian semi-permanent low. Occasionally storms enter the Arctic Ocean over northeastern Siberia or the Bering Straits. From time to time new storms develop to the north of the Alaskan mountains after primary storms have stagnated to the south.

d. Over the Polar Basin, many cyclones spiral in toward the Pole. Storms breaking off the Icelandic low usually move northeast to the Norwegian-Barents Sea and a primary track continues along 75°N. These frequent storms play an important part in the climate of the north European and Siberian coastlands. This primary track is joined by tracks from the Baltic, Black and Caspian Seas. Some storms stagnate near Novaya Zemlya, others regenerate and curve in towards the Pole.

e. Over North America, the most marked change in summer (July) is the northern displacement of the track of the Alberta lows. During this season the Prairie Provinces have one of the highest frequencies of cyclonic activity in the northern hemisphere. Most of the storms cross Hudson Bay to the Davis Strait-Baffin Bay area where they stagnate. Over the Atlantic, to the east of Iceland, the primary track is more zonal in July with a drop in the number of storms entering the Polar Basin. A well-defined path extends from the eastern Atlantic into Siberia at about 60°N.

f. In the Pacific sector, the main track in summer is well to the north of the Aleutians, with a maximum over the Bering Sea. Although fewer Atlantic storms enter the Polar Basin at this season, there is a high frequency of travelling disturbances along the northern coastal regions of Siberia which appear to be related at least in part to the strong temperature gradients at the margin of the heated land and the melting Arctic ice. The storms move mainly to the northeast, spiraling into the central Arctic where they stagnate. Approximately one third of the lows that enter the Beaufort Sea during this season are from northern Siberia.

g. There is a difference in the climatic importance of synoptic weather systems when the middle latitudes are compared with the Arctic Ocean. In the former regions, synoptic systems control the weather and climate by an ever-changing sequence of different air masses. Over the Arctic Basin in winter, cyclonic patterns generally do not influence the surface climate except so far as they control mixing in the inversion layer. Warm and cold spells in temperate latitudes are most often air mass phenomena (advection); over the Arctic Ocean cold spells are generally caused by radiation, not by advection, while milder surface conditions require vertical transport downward of warmer air from above the inversion. Sporadic invasions of warm maritime air do occur, however, sometimes into the Arctic Basin.

h. Frontal development occurs in summer, mainly along the continental coasts. Strong temperature contrasts develop because of the different absorption of solar radiation by land and ice. The land surface warms appreciably, but the ice absorbs only a small part of the insolation and cannot warm above the melting point. The summer storms generally develop in the continental coastal boundary but are not confined to any narrow strip. A broad zone of thermal contrasts may sharpen into fronts, the locations of which are determined both by the circulation and by the presence of heat sources and sinks. Such summer frontal cyclones bring the heaviest precipitation to the Arctic Ocean. The fronts are generally more distinct some distance above the surface. The cold air in contact with the ice often masks the existing temperature differences, especially in summer when a uniform surface temperature is found in all sectors. Above the surface layers, Arctic disturbances show similar features of cloud distribution to the usual models of middle latitude frontal-type cyclones.

204. WIND

a. Observations from drifting ice stations (Table 2-II) indicate that surface wind speeds over the Arctic Ocean are not very high. On the average the force is 4 to 5 m/sec (8 to 10 kt.). When an inversion (increase of temperature with height) is present, the surface layer is effectively isolated from the faster moving air above. It is this fact, in combination with the lack of topographic effects, which results in the low number of occurrences of strong winds. Although light winds predominate, strong winds may occur and persist for periods of one to three days. Wind

Table 2-II. Frequency Distribution of Wind Speed over Central Arctic Ocean (percent)

m./sec.*	0	1	2	3	4	5	6	7	8	9	10-14	15-19	20	No. of Obs.
Jan	11	7	8	10	13	12	8	8	6	4	10	2	1	564
Feb	10	6	11	15	17	15	9	5	5	1	6	0	0	548
Mar	6	6	8	18	22	15	7	6	4	2	5	1	0	585
Apr	6	5	15	15	17	15	8	7	5	4	3	0	0	479
May	7	5	11	16	16	15	11	7	6	3	3	0	0	744
Jun	5	5	9	15	13	15	11	9	6	4	7	1	0	669
Jul	4	3	9	12	13	16	10	9	9	6	8	1	0	609
Aug	4	4	7	11	11	15	11	11	8	5	11	2	0	570
Sep	8	4	9	13	15	15	8	10	5	4	7	2	0	545
Oct	7	5	9	12	12	12	10	9	7	4	11	2	0	586
Nov	9	7	10	13	16	15	7	6	6	4	6	1	0	607
Dec	11	10	14	14	17	12	6	5	4	3	4	0	0	607

*1 metre per second = 1.94 knots = 2.24 m.p.h.

speeds are critical in the Arctic because in addition to the winds intensifying the feeling of cold, they are responsible for blowing snow – the major deterrent to travel in winter.

b. The annual mean wind speeds are greatest at exposed coastal stations near cyclone tracks, and it is in these same locations that gales are most frequent, for example, at Jan Mayen, northern Norway to Dikson Island and Bering Strait (Tables 2-III, 2-IV). On the other hand, at sheltered locations or those remote from normal active storm tracks, the annual mean wind speeds are rather low, as at Eureka and Aklavik.

Table 2-III. Average Surface Wind Speed (mph) and Most Prevalent Direction
(mph = .868 knots = .447 metres per second)

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Yrs of Record	Note
Jan Mayen	N 20	N 21	N 20	N 18	N 13	N 14	N 12	N 13	N 14	N 16	N 19	N 19	17	10	(1)
Bear Island	SW 5	NE 5	NE 5	NE 5	SW 4	W 4	E 4	SW 4	NE 5	E 5	SW 5	SW 5	5	7	(1)
Vardo	SW 22	21	SW 21	19	NW 16	16	NW 13	14	NW 17	19	SW 21	21	18	28	(7)
Kola	SW 10	9	SW 9	8	SW 9	10	N 9	7	SW 8	9	SW 10	9	9	10	(7)
Tikhaya Bay	16	15	12	12	11	10	8	9	13	15	15	17	13	10	(7)
Yugor Strait	S 20	S 20	S 18	SW 18	NE, SW 16	NE 14	NE 13	N, SW 13	W 16	SW 20	S, SW 20	S 20	17	21	(6)
Dikson Island	S 18	S 20	S 18	S 16	NE 18	NE 16	NE 13	NE 13	S 16	S 16	S 16	S 20	15	7	(4)
Cape Chelyuskin	SW 16	SW 14	E 13	E 13	W 13	E, W 14	E 13	E 13	E 13	NE, SW 13	SW 13	SW 14	13	7	(3)

Table 2-III (Cont'd). Average Surface Wind Speed (mph) and Most Prevalent Direction
(mph = .868 knots = .447 metres per second)

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Yrs of Record	Note
Verkhoyansk	SW 1	2	SW 2	4	NE 6	7	NE 6	5	SW 4	3	SW 2	1	3	21	(7)
Wrangel Island	NE 11	N 11	N, NE 10	NE 9	NE 9	NE 7	E 9	NE 8	N, NE 13	N 15	N 15	N 11	9	10	(6)
Nome	NE 10	NE 11	NE 10	NE 10	NE 9	W 9	SW 9	SE 10	N 10	NE 10	NE 11	NE 10	10	18	(6)
Barrow	NE 7	NE 11	NE 10	NE 11	NE 11	NE 11	SW 11	NE 13	NE 14	NE 14	NE 13	NE 11	11	25	(6)
Aklavik	S 6	S 6	NW 7	N 7	N 7	N 8	NW 7	NW 7	NW 7	NW 6	NW 5	NW 6	7	10	(6)
Sachs Harbour	N 13	E 12	SE 11	E, SE 13	E 13	N, E 13	NW 13	SE 14	E 15	E 15	E 13	E 12	13	5	(5)
Mould Bay	NW 11	NW 9	N 8	N, NW 8	NW 12	NW 13	NW 12	S, NE 11	NW 12	NW 11	NW 10	NW 9	NW 13	10	(5)
Cambridge Bay	W 12	W 11	W 11	N, NW 12	NW 13	N 13	N 13	E 13	E, NW 13	NW 14	W 12	W 11	12	10	(5)
Isachsen	N 11	N 8	N 7	N 8	N 10	N 10	NW 11	N, SW 10	N 10	N 11	N 9	N, NW 10	10	10	(5)
Resolute	NW 12	E 12	NW 10	NW 11	NW 12	NW 13	NW 12	NW 12	NW 13	NW 13	NW 11	NW 10	12	10	(5)

Table 2-III (Cont'd). Average Surface Wind Speed (mph) and Most Prevalent Direction
(mph = .868 knots = .447 metres per second)

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Yrs of Record	Note
Eureka	E 7	E 7	E 5	E 6	NW 8	NW 11	NW 11	NW 10	NE 8	E 7	E 6	E 5	8	10	(5)
Alert	W 5	W 5	W 5	W 5	W 5	W, NW 7	NE 8	NE 6	NE 6	W 7	W 6	W 5	6	10	(5)
Thule	E 9	E 9	E 7	E 7	E, W 7	W 7	W 7	W 6	E 8	E 10	E 9	E 8	8	11	(5)
Upernavik	NE 5	NE 4	E 4	E 4	E 5	N 6	N 4	N 4	E 5	E 6	E 6	NE 6	5	30	(6)
Angmagssalik	E 7	N 6	W 5	E 6	S 5	S 5	E 5	S 5	S 5	NE 6	NE 6	NE 6	6	15	(1)
Scoresbysund	NE 5	NE 5	NE 5	NE 4	NE 3	S 3	S 3	S 3	NE 3	NE 4	NE 4	NE 4	4	12	(6)
Grimsey	SE 14	NE, E 13	E 10	E 9	E 7	E 6	E 6	E 6	E 8	E 9	SE 10	E 13	8	18	(2)

NOTES: 1. Mean of 0800 and 1400 observations.
2. Mean of three observations.
3. Wind frequencies computed without calms.
4. Mean of 0700, 1300 and 2100 hrs observations.
5. Mean of hourly observations.
6. Most prevalent directions combined quarterly: (Dec-Jan-Feb, etc.).
7. Directions missing or incomplete or unknown.

Table 2-IV. Frequency of "Gales" per Month and Year

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Yrs of Record	Note
Jan Mayen	5	4	4	3	2	1	*	*	2	3	5	4	33	–	(1)
Tromso	2	2	1	*	*	*	0	*	*	1	2	1	9	26	(1)
Vardo	5	5	4	3	2	1	1	2	2	3	5	5	38	31	(1)
Kola	4	4	4	2	3	2	2	1	2	3	5	4	36	18	(1)
Tikhaya Bay	10	9	7	5	3	3	2	2	4	6	8	11	69	10	(1)
Yugor Strait	10	9	8	8	7	5	3	2	5	7	10	9	82	26	(1)
Dikson Island	11	19	8	7	5	3	1	3	5	6	9	8	75	19	(1)
Cape Chelyuskin	8	4	4	2	2	4	3	2	3	3	6	6	47	8	(1)
Verkhoyansk	*	*	*	*	*	2	2	1	1	*	*	0	7	17	(1)
Wrangel Island	8	3	6	2	3	3	1	2	8	7	8	4	55	3	(1)
Nome	4	2	3	3	1	*	*	1	1	2	1	4	21	10	(1)
Barrow	2	1	*	1	1	0	1	1	2	5	3	2	19	5	(1)
Sachs Harbour	1	*	*	1	*	*	*	1	*	1	1	1	6	12	(2)
Cape Parry	1	1	*	*	0	0	0	*	*	1	*	*	3	10	(2)
Mould Bay	2	1	1	1	*	*	*	*	1	1	1	2	10	12	(2)
Holman	2	1	3	2	1	1	*	*	1	2	2	2	17	12	(2)
Coppermine	*	0	0	*	0	0	0	*	0	*	0	*	*	12	(2)
Cambridge Bay	1	*	*	*	*	*	*	*	*	1	*	1	3	12	(2)
Isachsen	5	3	3	1	1	1	*	*	*	2	2	3	21	12	(2)
Resolute	4	4	2	2	2	1	1	3	1	3	3	3	29	12	(2)
Eureka	*	*	*	*	*	*	*	*	*	*	*	*	*	12	(2)
Clyde	1	1	0	*	*	*	0	0	*	*	*	*	2	12	(2)
Alert	3	3	2	3	2	*	2	1	1	3	2	3	25	12	(2)
Cape Dyer	4	3	2	1	1	*	*	*	1	3	2	3	20	8	(2)
Thule	4	4	1	1	3	2	3	3	4	2	2	*	28	3	(1)
Upernavik	1	2	1	1	2	1	2	1	1	2	2	*	15	10	(1)
Angmagssalik	7	5	4	2	1	1	*	1	3	2	4	5	36	10	(1)

Table 2-IV (Cont'd). Frequency of "Gales" per Month and Year

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Yrs of Record	Note
Scoresbysund	10	6	9	10	6	4	6	3	8	10	8	6	84	2	(1)
Grimsey	3	2	2	1	*	*	0	*	1	2	2	2	15	14	(1)

NOTES: 1. Figures give mean number of days with gales (where a day with gales is one on which the surface wind speed at some time equals or exceeds 32 mph (28 knots))
2. Mean number of days with gales (as above but speeds equal to or exceeding 39 mph (34 knots))
3. *indicates less than 0.5 days.

c. There are certain regional characteristics in the Arctic wind systems over land. Eastern Siberia experiences a monsoonal change in wind direction. At Verkhoyansk, for example, winds are light from February to May. During these months when the anticyclone is well developed over the continent, winds along the coast (at Yugor Strait for example) are strongest. During the summer months, the thermal low pressure system shows greatest development over the interior. Along the coast, winds are weakest during these months and strongest in the interior.

d. In the Alaska area, the Bering Strait and the land areas immediately to the east and west of it, being low in elevation, present no obstacle to the free interchange of air between the Arctic Basin and the region of the Bering Sea. During the winter, with the well developed Aleutian Low, the prevailing wind through this region is northerly. The wind regime of Alaska, like that of eastern Siberia, is to some extent monsoonal in character. In the warmest months, a thermal low develops over the interior of Alaska whereas, in winter, high pressures are prevalent.

e. Wind studies at several Arctic sites reveal that although high surface winds are usually associated with strong pressure gradients, they may often occur due to local effects. Many stations show locally preferred wind directions due to topography, and surface wind data from Arctic coastal stations must not be taken as typical of the wind speed and direction over a larger area. Certain locations in Greenland are good examples of this – Thule in the northwest and Narssarssuak in the southwest both have local strong winds, closely associated with descent of the air from the inland ice-cap. Alert in Ellesmere Island, Barter Island on the north coast of Alaska, and Novaya Zemlya all experience local strong winds. At some locations, such as Barter Island, these strong winds associated with the local effects may be felt as far as 100 miles to sea.

205. TEMPERATURE

a. The most common misconception of the Arctic is that the land areas are covered with eternal ice and snow and that there is everlasting winter with intense cold. A large part of Greenland is a striking example of an ice-covered land possessing these qualities and from it, the rest of the north has been pictured by analogy. The high elevation of Greenland and Ellesmere Island highly favours glaciation. In general, however, other Arctic lands possess neither of these characteristics and over a large portion of the Arctic the scanty snows melt rapidly with the approach of summer. Most of the little snow that does fall is soon swept by the wind into gullies and the lee of hills, so that over much of the Arctic lands the winter snow cover is quite thin. Next consider the intense cold: at the North Pole the lowest temperatures do not fall below −55°C, a figure that is occasionally reached in some parts of the Canadian Prairies. The coldest observed temperature on the surface of the earth before 1957 was recorded at Verkhoyansk, near the Arctic Circle in eastern Siberia and well over 1,500 miles (2,400 km) from the geographic pole. This station enjoyed the doubtful honour of experiencing colder winter weather than any other known place in the world. Only the central Antarctic, occupied since 1957, is colder (−90°C) than the record of −68°C at Verkhoyansk.

b. In Eurasia, winter temperatures (Fig. 2-VI) show a marked decrease as the observer moves from the warm coastal areas of Scandinavia towards northeastern Siberia, until around Verkhoyansk the January mean is −48°C. The reason why this area has the most extreme winters known in the northern hemisphere is readily understood from its geographic location. The warming influence of the North Atlantic does not extend into the frozen continent; the Pacific Ocean has no appreciable effect, since ranges of hills intervene and the winds are prevailingly offshore; the ice-covered Arctic Ocean certainly cannot modify the harsh conditions and the lofty ranges of central Asia check any influence from the warm Indian Ocean far to the south. The characteristic lag of seasons, so highly pronounced on the Arctic coasts and conspicuous at any locality with maritime influence, is almost totally absent. The temperature curve follows more nearly that of insolation and April is as warm as October. In the interior of Canada the same characteristics are evident but, since the area is not comparable to the vastness of the Siberian continent, the feature is less pronounced.

c. The Siberian winter is by no means as unpleasant as its extreme temperatures might suggest; the air is often calm and the skies clear. Danger to man and beast occurs only when the wild "buran" or "purga" blows. Such fearful blizzards also occur in the interior of Canada.

d. The irregularities of the winter isotherms over the Arctic Ocean are produced by the influence of the Atlantic and Pacific Oceans. In the North Atlantic, the isotherms are pushed far northward and it is here that one finds the greatest positive anomaly of temperature in the world (the greatest departure from latitudinal average). The winter temperatures in the vicinity of Bering Strait are influenced by the open waters of the Bering Sea. North of the Strait the influence is limited to a small area in which large local differences occur with different wind directions. Large and rapid temperature fluctuations are otherwise not a common feature over the Arctic Ocean. During the greater part of the year the area is covered by a relatively thin layer of cold air, which to a great extent is isolated from the atmosphere above. The air temperature near the surface is primarily dependent on the temperature of the ice surface itself. On rare occasions, however, warm air from the North Atlantic may raise the winter temperature near the North Pole by as much as 30 degrees C. After the warm air import has ceased, radiation control again dominates the surface temperature, which will show an equally drastic drop. Strong winds may also cause higher surface temperatures by breaking down the temperature inversion and mixing the warmer air from above with that near the cold surface. Renewed cooling follows every slackening of wind.

e. The winter temperatures over the pack ice remain nearly constant for a considerable time. This "flat" minimum represents the temperature at which the loss of heat from the snow and ice surface by radiation balances the amount of heat which is conducted to the surface from the water under the ice. It also depends on the heat transported into the Arctic by warm air advection in advance of cyclones. During the long periods of infrequent cyclone activity in winter, heat transfer to the surface from the atmosphere is small, since the eddy conductivity is very small in the inversion layer.

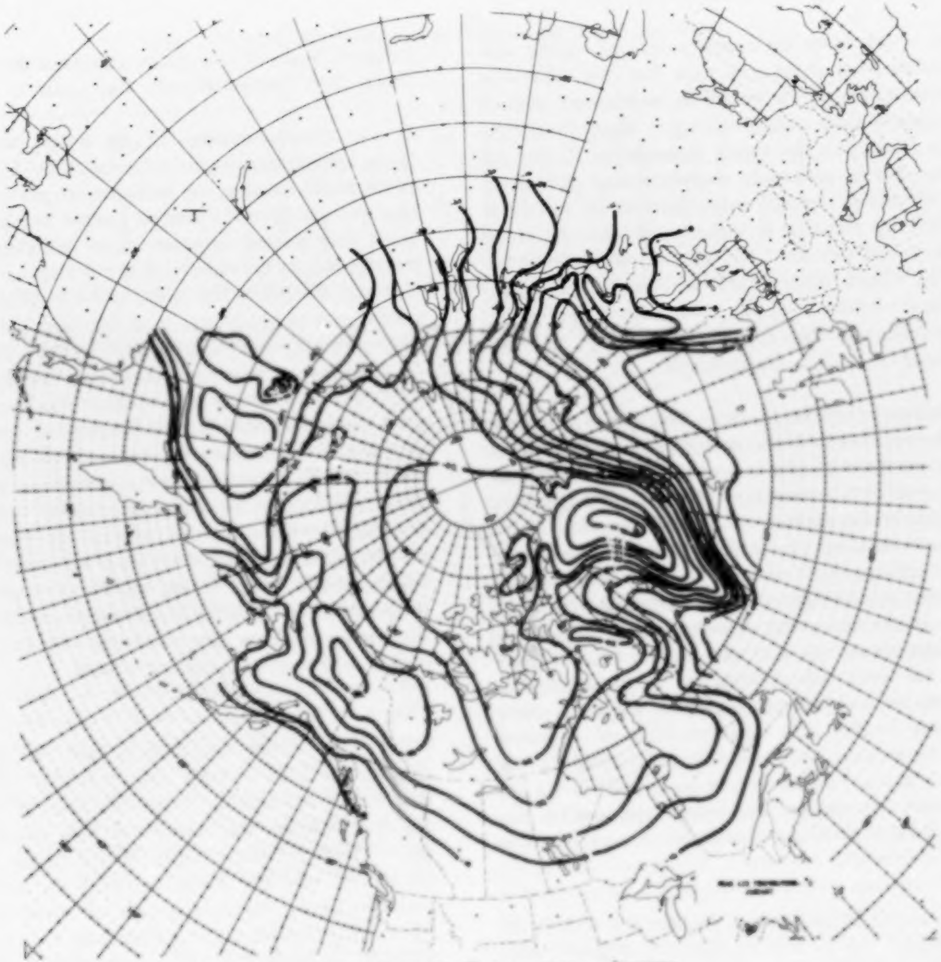


Figure 2-VI. Mean Air Temperature – January

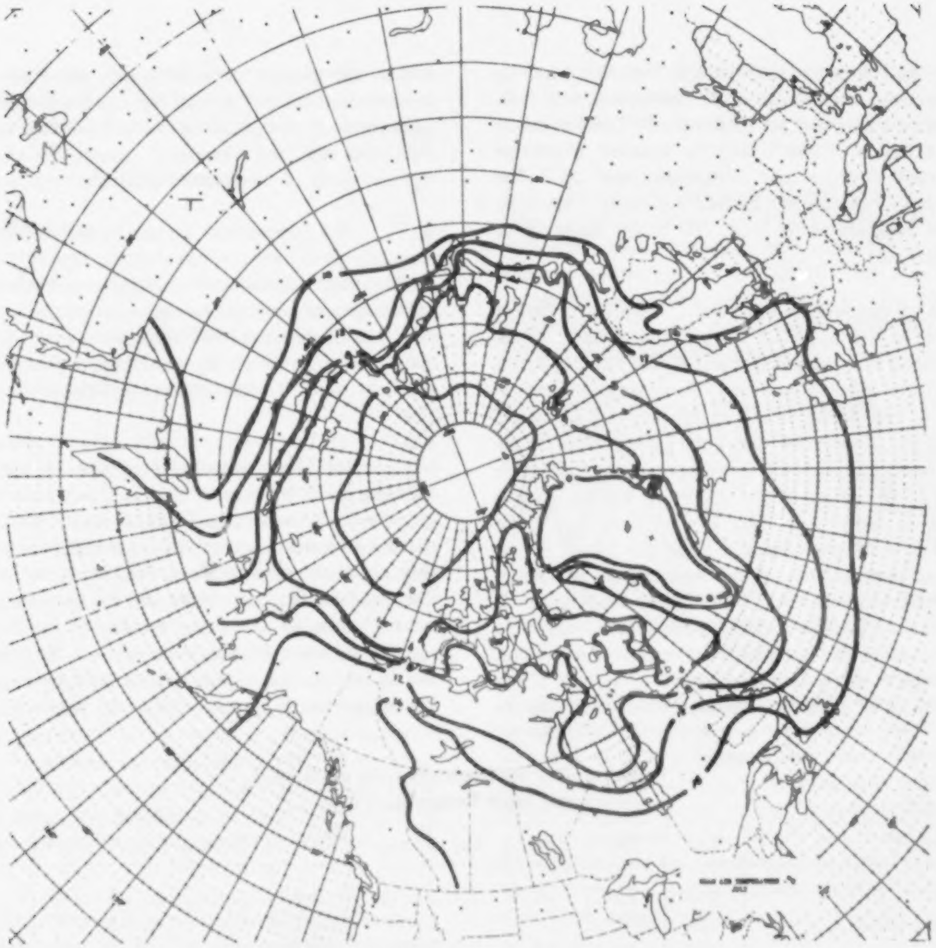


Figure 2-VII. Mean Air Temperature – July

f. Theoretically minimum air temperatures over the pack ice occur when the net radiation loss is balanced by transport of heat from the water. Thus, minimum temperatures of about −40°C are common while over thick ice extremes of −50°C may be recorded. Maximum winter temperatures under overcast, calm conditions reach −25°C. The extreme maximum temperatures are nearly linear functions of the wind speed, increasing with increasing wind speed due to the transport of heat from above the inversion.

g. The presence, or nearness, of open water in the winter half of the year, is reflected in the mean air temperature pattern. Broad tongues of warmth extend into Barents Sea and Baffin Bay and across Bering Strait. The strongest influx of heat by cyclonic activity occurs in the Atlantic section of the Arctic Ocean in January and February. From April until June the temperature rises quite rapidly, until the ice begins to melt. The mean summer surface temperatures remain fairly constant, conforming to the nature of the underlying surface. Almost all regions are warmest in July (Fig. 2–VII). Temperatures close to the melting point prevail over the pack ice and along the fringes of the Greenland ice-cap and outer islands of the Archipelago. Maximum temperatures in the Arctic Basin do not exceed 5°C. An examination of large departures of monthly mean temperatures from normal values for 20 coastal or island stations, with twenty or more years of observations, showed that the greatest departures are found in winter (from November to April) and small departures are most probable in July. In winter, the greatest departures were observed in the Kara Sea, the smallest in the East Siberian Sea. In summer, the greatest departures from normal temperatures were observed on the coasts of the peripheral seas and decreasing toward the north. The results of a regional study of temperature departures are summarized in Table 2-V.

h. The temperature inversions observed in all Arctic regions are especially prominent over the pack ice. During the darkness of winter in the high Arctic the diurnal variation in temperature is irregular and the maximum and minimum temperatures can occur at any time during the 24 hours of the day. Variations are almost wholly due to changes in cloud cover or wind speed. Temperatures rise when cloud cover increases or winds strengthen, and fall when winds decrease or skies clear.

j. Small temperature variability in the summer is a characteristic common to all stations in the inner Arctic Ocean. The temperatures over the pack ice never deviate far from the freezing point. The number of days with maximum temperature slightly above the freezing point is very nearly the same all along the latitude of 75°N – around 40 days. The diurnal ranges are smaller and the inter-diurnal changes are less in summer than in any other season. Warm air from inland is often transported a considerable distance from the coast but, in passing over the icy waters, it is cooled so effectively by contact with the ice that a sharp inversion is formed. Hence, the warm air current flows at some

Table 2-V. Average Departure from the Normal of Monthly Mean Temperature (Deg. C.)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wrangel Island	2.4	1.8	2.1	2.1	1.5	0.9	0.5	0.7	1.2	2.0	2.7	1.7
Central Region of Arctic Basin:												
Western Sector	4.4	3.8	3.0	2.3	1.4	0.9	0.5	0.8	1.8	2.7	3.4	4.2
Eastern Sector	2.6	2.3	2.3	2.3	1.3	0.5	0.3	0.7	1.1	2.0	2.8	2.8

distance above the ground and has practically no influence on the surface temperature. Considerably higher temperatures are found on the coast, and the change from coastal to maritime conditions takes place within a very short distance.

206. FOG AND VISIBILITY

a. The range of visibility varies greatly in the Arctic. Arctic air masses are pure and the visual range may be very great. Poor visibilities in the lower layers of the atmosphere result from the presence of falling precipitation, fog or blowing snow. Haze and smoke pollution of air masses as they occur in lower latitudes are rare in the Arctic.

b. During the warmer months, the most common type of fog is caused by the advection of relatively warm and moist air over the melting ice and cold water. When the air moves in such a way that it is cooled by contact with the colder underlying surface at a temperature below its dew point, it can no longer hold the excess moisture which condenses to form mist or fog. When the air near the surface is very stable, the fog will be shallow. On the other hand, turbulence in the lower levels of the air may give conditions under which this excess moisture becomes visible as low stratus clouds. The areas which are most favourable for the formation of this type of summer fog or low clouds are the open waters of the Kara, Laptev, East Siberian and Chuckchi Seas. Fifteen to twenty days with fog is a normal condition for these areas during the summer months (Table 2-VI). This advection type fog occurs most frequently over coastal waters adjacent to a local cold-air source or over open leads in the pack ice. Over the Arctic Basin it is extremely frequent and widespread during the period when the ice surface is melting.

c. Any analysis of the frequency of occurrence of fog in the Arctic is made difficult because the data from various regions is not based on a standard definition of what constitutes a day with fog. Table 2-VI contains data with fog defined in several different ways according to the resulting visibility. Thus, although it is useful for indicating annual variations at each location, regional comparisons are somewhat unreliable.

d. During the cold season, a less important type of fog known as "steam fog" or "Arctic sea smoke" occurs when very cold air moves over open water. It occurs only when the contrast between air and water temperatures is very great. This type of fog occurs most frequently over rivers, unfrozen lakes, open leads or polynias in the Arctic ice. Over the Arctic Basin steam fog serves the important purpose of indicating the presence of open water.

e. Another winter phenomenon is the occurrence of "ice fog". This is defined as a type of fog composed of suspended particles of ice which occurs at very low temperatures, mainly below −30°C, and usually during clear, calm weather at high latitudes. It occurs locally in the vicinity of human habitation, herds of animals, vehicular or aircraft operation and open water areas of fast running streams.

f. During the winter months, blowing snow is the most common cause of reduced visibilities, particularly in the more unprotected continental or insular locations. The frequency and severity of blowing snow is of course related directly to the frequency of high winds and the presence of new or powdery snow cover. Much of the snow of the Arctic falls in the form of loose granular flakes which are very readily whipped up by even relatively light winds. Observations show that with winds in excess of 15 mph, blowing snow is nearly always present in some degree in the cold Arctic. From December to April the visibilities at most Canadian Arctic Stations are reduced to six miles or less in blowing snow about one-third of the time. In the case of winds over 30 mph, more than eighty percent are associated with visibilities lower than three miles.

g. As long as no restrictions such as fog, precipitation or blowing snow are present in the Arctic atmosphere, visibilities are remarkably good. The records of many travellers are filled with accounts of the extreme range of visibility, and indeed it is not uncommon to see dark mountains 100 miles (150 km) distant. On the other hand, the lack of contrast, particularly where all surface objects are covered with new snow, results in the inability to distinguish objects close at hand. The addition of a uniformly overcast sky to an unbroken snow landscape gives rise to the condition usually referred to as "Arctic white-out".

h. The frequent well-marked temperature inversions of the Arctic region explain the many accounts of mirages. Objects that are known beyond any doubt to be below the horizon, are not infrequently visible as mirages and the periods of daytime and twilight are lengthened as the normal index of refraction is altered. The inversion may also interfere with the identification of landmarks through distortion, and estimation of vertical distances is made much more difficult.

207. CLOUD

a. The general character of cloud cover over the Arctic differs considerably from that considered typical for most temperate regions. The uniform and contourless stratus clouds, which are by far the most frequent type observed, give to the Arctic its reputation of a dull and monotonous appearance. Over the Arctic Ocean during the summer, the low stratus type of cloud constitutes from 70 to 80 percent of all cloud observed. The reason is the continuous cooling of the air from below over the pack ice fields and the presence of a source of moisture in the surface melt water. These summer clouds are extremely uniform, extending as large sheets over much wider areas than other cloud types. Along the coast in more southerly locations, the stratus clouds are proportionately less frequent. In these regions the cloud decks tend to be more often broken up by convective currents, with a resulting increase in the proportion of stratocumulus cloud reported.

b. In the Norwegian Sea, mean cloudiness is high throughout the year, with a slight maximum in the summer even though this is the season with the lowest cyclone frequency. For example, the mean cloudiness at 74°N, O°W is 80 percent in January, but 90 percent in July (Figs. 2-VIII and 2-IX).

c. Over the Arctic Ocean the cloud amount is lowest in winter and spring when the water content of the very cold air is too low for cloud formation. A further characteristic of this area is that the seasonal change in cloudiness takes place over a very short transitional period. Similar abrupt changes are found only in monsoon areas when a complete changeover takes place in the circulation pattern.

d. Areas showing relatively high cloud amounts in winter are the Norwegian and Barents Seas, where the January mean cloudiness exceeds 80 percent. These percentages decrease to below 70 percent in the Kara Sea, 50 percent in the Laptev Sea, to about 40 percent in the East Siberian and Beaufort Seas (Fig. 2-VIII). With few cyclones penetrating eastward beyond Novaya Zemlya, and little or no surface moisture, only thin middle clouds and cirrus clouds prevail. The main feature of the winter cloud pattern over the North American continent is the gradual decrease in cloudiness towards the north.

208. PRECIPITATION

a. Precipitation over most of the Arctic is very light and the annual amounts are so small that the region would be described as a desert or semi-desert if it were located in more southerly latitudes. Over the Polar Basin the annual precipitation amounts average less than ten inches (250 mm), while over the Siberian-American portion of the Arctic Ocean and the northern part of the Canadian Archipelago the amounts are generally of the order of four inches (100 mm) or less (Table 2-VII). The greatest portion of the annual total precipitation falls in the summer as rain, although the rate of fall is usually light and in most cases would be classed as drizzle rather than rain. Heavier showers may occasionally occur.

b. Over much of the Polar Basin snow may be expected during all months of the year, and in the far north even in summer the number of days with snow may exceed the number of days with rain. Because of the low moisture concentration possible at very low temperatures, however, the winter snow is very fine and when it occurs on windy days its measurement becomes very difficult. Freezing rain and freezing drizzle can also occur in the summer months. Available data indicate that on the average freezing precipitation occurs less than ten hours per year. The rate of accumulation is quite low compared to the rapid build-up of ice that can occur in more southerly latitudes.

c. The characteristics of the snow cover, such as thickness and duration, have important climatic effects on the heat and moisture exchange at the surface. Over the central Arctic Ocean, the snow cover becomes established in late August. The average thickness of the scoured and drifted snow cover may be about 14 to 16 inches (350 – 400 mm) by late spring. Steady snow melt usually begins by the middle of June – caused by solar radiation – and, although there are marked differences from year to year, the pack ice is usually snow-free by the middle of July.

d. South of latitude 75°, the annual precipitation amounts are higher. Some points in Greenland and the European Arctic for example present an annual precipitation in excess of 40 inches (1000 mm). As would be expected from the high frequency of cyclonic activity, the Norwegian Sea area has the greatest annual precipitation of all regions north of the Arctic Circle, although a secondary maximum of cyclonic activity in Baffin Bay accounts for fairly high precipitation amounts along the west Greenland coast and the eastern coasts of the Canadian Arctic Archipelago.

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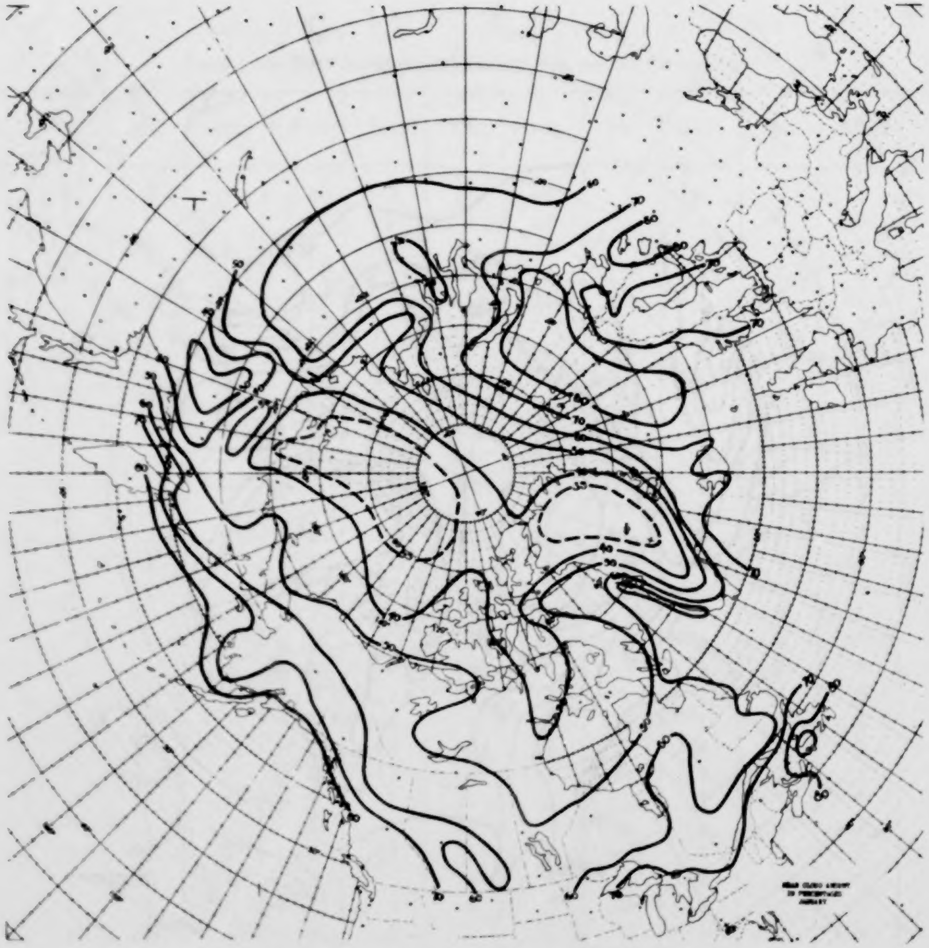


Figure 2-VIII. Mean Cloud Amount in Percentages – January

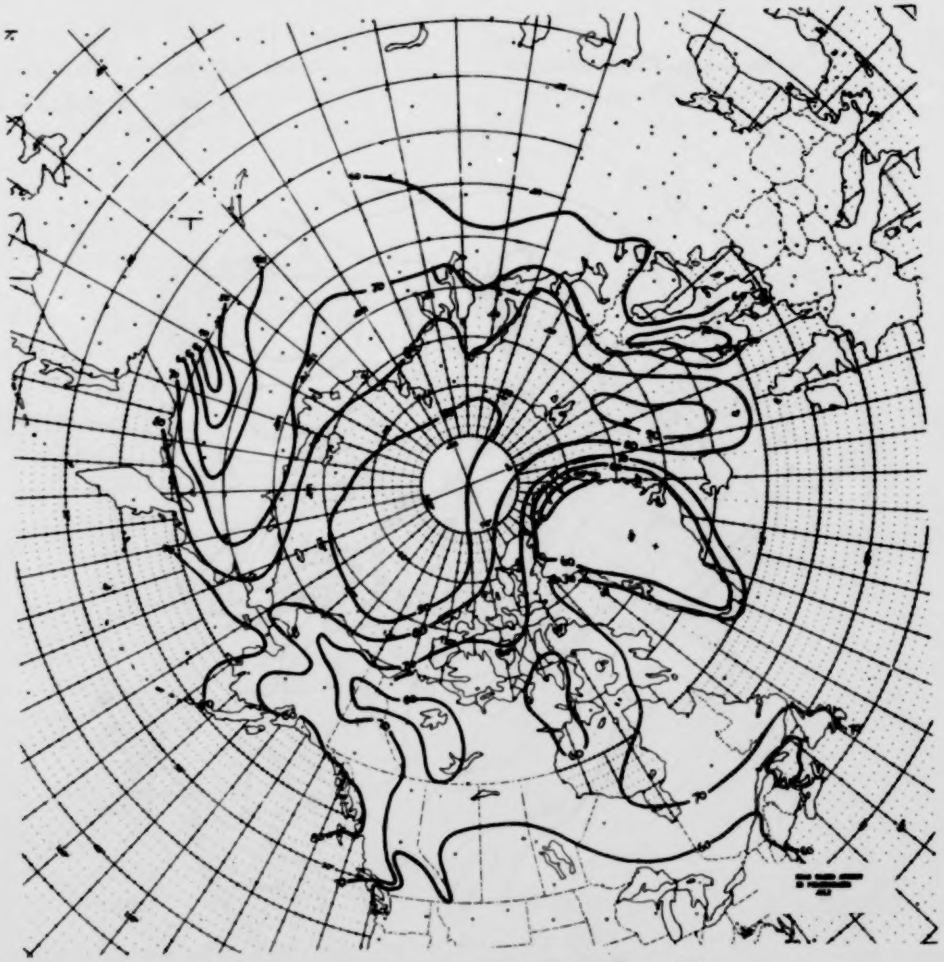


Figure 2-IX. Mean Cloud Amount in Percentages – July

Table 2-VI. Mean Number of Days with Fog per Month and Year

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Yrs of Record	Note
Jan Mayen	3	3	4	4	8	14	17	11	9	6	4	3	86	14	(1)
Green Harbour	*	1	*	*	*	3	4	3	1	1	0	0	13	7	(1)
Mossel Bay	2	5	4	5	3	2	11	3	5	1	1	2	44	9	(1)
Tromso	1	1	1	1	1	1	2	2	2	1	1	1	14	46	(1)
Bear Island	1	2	3	5	7	9	19	15	12	4	3	1	82	–	(1)
Vardo	*	*	0	*	1	3	7	5	1	*	*	*	17	44	(1)
Kola	1	*	*	*	1	1	3	4	2	1	2	1	16	10	(1)
Tikhaya Bay	6	7	9	9	9	10	15	16	6	5	4	5	100	10	(5)
Rudolfa Island	2	*	4	8	5	13	24	24	14	5	2	2	104	4	(5)
Vaigach Island	6	5	7	8	9	15	17	16	11	5	3	4	106	14	(5)
Yugor Strait	4	5	6	7	10	14	16	14	8	7	5	4	99	26	(1)
Dikson Island	4	4	5	7	7	15	20	16	11	5	3	2	99	18	(1)
Domashni Island	3	6	7	7	4	6	20	20	13	4	2	1	92	4	(1)
Cape Chelyuskin	2	4	8	8	8	13	24	24	13	6	5	2	117	7	(1)
Tiksi Bay	3	3	3	5	5	14	12	8	5	4	2	1	65	7	(1)
Verkhoyansk	3	2	1	*	1	*	1	5	4	1	2	4	24	9	(1)
Cape Shalaurova	4	7	8	8	8	15	18	15	6	3	3	6	101	10	(1)
Wrangel Island	2	2	3	5	7	12	14	14	6	3	4	3	75	13	(1)
St Paul Island	1	2	2	3	5	7	10	8	3	*	*	*	42	28	(3)
Nome	3	1	1	1	3	5	3	2	*	*	1	2	23	15	(3)
Kotzebue	1	1	1	1	4	5	3	1	1	1	1	1	21	21	(3)
Barrow	2	1	1	3	8	13	13	11	5	4	2	2	65	20	(3)
Barter Island	1	1	2	3	8	11	15	15	11	3	3	1	74	13	(3)
Aklavik	1	1	*	*	1	1	1	1	2	1	1	*	11	20	(1)
Sachs Harbour	*	*	1	3	6	9	16	14	18	4	2	2	65	12	(1)
Cape Parry	2	3	2	3	9	12	12	11	8	3	2	2	69	10	(1)
Mould Bay	1	2	3	3	3	3	3	7	6	3	1	*	34	13	(1)
Holman	2	1	1	1	1	3	6	4	2	1	*	*	20	18	(1)
Coppermine	*	1	*	2	3	3	2	2	2	1	1	1	18	20	(1)

Table 2-VI (Cont'd). Mean Number of Days with Fog per Month and Year

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Yrs of Record	Note
Cambridge Bay	1	2	1	2	5	3	3	4	3	3	2	2	30	18	(1)
Isachsen	1	2	5	5	3	3	6	8	8	5	2	1	49	12	(1)
Resolute	1	2	1	1	2	5	7	8	5	1	1	•	34	13	(1)
Eureka	1	1	1	1	•	•	•	1	2	2	1	1	10	13	(1)
Arctic Bay	•	•	1	1	1	•	2	2	1	•	•	•	8	20	(1)
Clyde	1	1	1	1	2	2	5	5	1	•	1	1	18	15	(1)
Alert	1	•	1	1	7	7	8	9	6	3	2	1	45	10	(1)
Cape Dyer	5	5	2	3	12	11	8	11	9	7	5	3	81	9	(1)
Thule	1	•	1	1	2	4	4	2	1	•	•	•	16	6	(2)
Upernavik	2	1	1	2	5	9	11	7	2	1	•	1	42	31	(4)
Angmagssalik	1	1	2	4	9	11	11	9	5	3	2	1	59	30	(1)
Scoresbysund	4	6	6	8	15	14	11	8	9	5	4	6	96	11	(4)
Grimsey	•	1	2	2	5	5	9	6	3	•	1	1	35	14	(1)

NOTES: 1. A day with fog is defined as a day on which visibility was lowered by fog to less than 5/8 mile (1 km; 1/2 nm) for some part of the day.
2. As in Note 1, but visibility less than 1 mile (0.6 km).
3. As in Note 1, but visibility 1/4 mile (0.4 km) or less.
4. As in Note 1, but visibility less than 3 miles (4.8 km).
5. Visibility criteria not specified.
6. •indicates less than 0.5 days.

Table 2-VII. Mean Monthly and Annual Precipitation (mm)
(1 mm = 0.0394 inches)

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Yrs of Record
Jan Mayen	38	43	28	23	13	15	20	28	64	56	36	25	389	7
Bear Island	28	36	31	21	21	24	21	26	41	36	25	28	338	15
Green Harbour	33	31	28	23	13	13	18	20	23	31	25	41	299	14
Dikson Island	5	3	5	5	5	18	20	41	41	13	8	5	169	17
Cape Chelyuskin	3	3	3	3	3	2	28	28	10	8	5	3	99	22
Verkhoyansk	5	3	3	5	8	23	28	25	13	8	8	5	134	31
Wrangel Island	5	5	5	5	5	10	15	23	13	10	3	5	104	11
Barrow	5	5	3	3	3	8	23	18	13	15	8	8	112	25
Sachs Harbour	2	2	4	3	6	5	25	17	16	11	5	4	100	10
Cape Parry	7	7	5	18	10	22	23	36	30	28	9	9	204	5
Mould Bay	3	2	3	3	6	4	18	18	11	6	3	3	80	13
Holman	6	6	7	9	8	7	20	26	20	17	8	6	140	20
Coppermine	12	8	13	10	12	20	34	44	28	26	15	11	233	30
Cambridge Bay	8	4	6	5	6	13	25	25	16	13	10	6	237	32
Isachsen	2	1	1	4	8	4	21	20	18	9	4	2	94	13
Resolute	3	3	3	6	9	13	24	32	19	16	6	4	138	14
Eureka	3	2	2	2	3	3	14	12	11	7	2	2	62	14
Arctic Bay	8	5	7	6	8	12	20	25	22	17	8	6	144	24
Clyde	10	7	6	10	13	10	23	32	33	34	22	6	206	19
Alert	6	6	6	6	9	12	15	28	30	16	6	7	147	10
Cape Dyer	70	54	28	25	51	41	27	77	83	76	51	92	670	5
Thule	8	9	5	3	6	7	18	14	16	18	13	6	123	10
Upernavik	8	8	10	16	16	16	28	30	28	30	28	16	234	30
Prins Christians Sund	185	208	300	200	242	208	158	165	200	242	147	277	2532	5
Angmagssalik	79	76	74	58	43	46	36	58	76	120	71	69	803	30
Scoresbysund	48	36	23	36	10	20	38	18	46	25	28	51	379	5
Grimsey	15	18	13	10	18	36	36	58	51	64	46	23	388	13

CHAPTER 3

OCEANOGRAPHY

SECTION I – GENERAL DESCRIPTION

301. DEFINITION

a. The Arctic Ocean surrounds the North Pole and is defined by the bordering land masses of Siberia, Alaska, Canada and Greenland. In an oceanographic sense it is a single large basin connected primarily with the Atlantic Ocean through two other major Arctic seas, Baffin Bay and the Greenland Sea. The water characteristics within these smaller basins can be traced in large part to North Atlantic water characteristics which have been modified through surface-acting processes associated with the unique climatic conditions of the Arctic. The characteristics of the peripheral continental Arctic seas are highly variable and are analysed in greater detail in Section II of this chapter.

302. BATHYMETRY

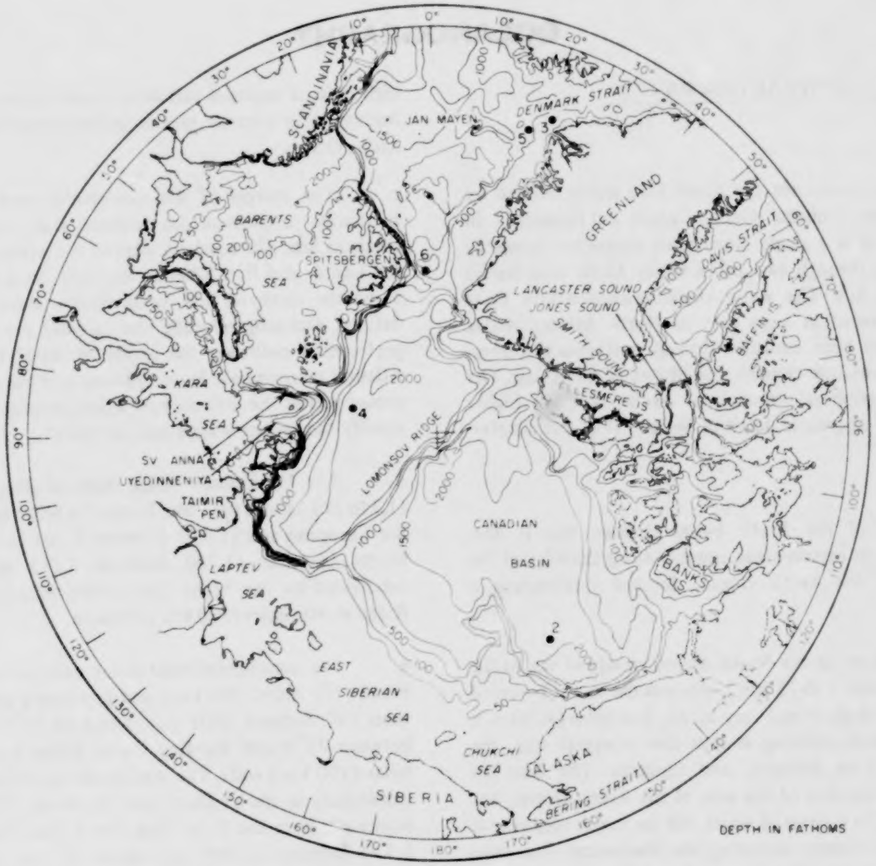
a. The bathymetry of the Arctic basins (Figure 3-1) is now generally known, though in certain areas, notably along the edge of the continental shelf within the Arctic Ocean, detailed information is lacking.

b. The continental shelf on the North American side of the Arctic Ocean is narrow, 31-47 miles (50-75 km.), whereas the sector bounded by Europe and Siberia is shallow and very broad, 250 miles (400 km.), with peninsulas and islands dividing it into five marginal seas, the Barents, Kara, Laptev, East Siberian, and Chukchi. The Eurasian marginal seas occupy 36 percent of the area of the Arctic Ocean, but contain only 2 percent of its volume of water. All the major continental rivers reaching the Arctic Ocean, excepting the Mackenzie, flow into these seas. The combination of the marginal seas characterized by a high ratio of exposed surface to total volume, and substantial input of freshwater in summer, greatly influences surface water contitions in the Arctic Ocean.

c. The margin of the continental shelf is indented by numerous submarine canyons in the northern Kara Sea and sea valleys in the Chukchi Sea. The northern edge of the continental shelf, particularly in the Laptev and East Siberian seas and along the Canadian Archipelago, is poorly surveyed and undoubtedly there are canyons yet to be defined. Oceanographically the canyons are important as they act as preferential pathways for egress of water from the relatively warm Atlantic intermediate layer onto areas of the continental shelf, where it comes within the influence of strong mixing processes, and can locally modify the surface waters and ice cover.

d. The Lomonosov Ridge with sill depth of about 760 fathoms (1,340 m.) divides the Polar Basin into two deep basins, the Eurasian on the European side (1,970 fathoms: 3,603 m.) and the Canadian on the North American (1,780 fathoms: 3,255 m.). The latter is further subdivided by the Alpha Rise, which runs parallel to the Lomonosov Ridge at 300 miles (500 km.) distance.

e. The continental shelf along east Greenland, south to 77°N, is broad (185 miles: 300 km.) and contains a system of banks no deeper than 110 fathoms (201 m.). South of 77°N the shelf narrows until between 75°N and the Kap Farvel (Cape Farewell) it is less than 60 miles (100 km.) wide. The shelf is marked by several deep indentations, particularly in the southern part. At about 79°N, the Greenland Sea is separated from the Polar Basin by a rise, with a sill depth of about 1,530 fathoms (2,798 m.). South of the rise, the Greenland Sea contains two deep basins. At 71°N, the Jan Mayen Ridge extends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170°
180°
SCANDINAVIA
JAN MAYEN
DENMARK STRAIT
GREENLAND
DAVIS STRAIT
LANCASTER SOUND
JONES SOUND
SMITH SOUND
BAFFIN IS
ELLESMERE IS
BARENTS
SEA
SPITSBERGEN
KARA
SEA
SV ANNA
UYEDINNENIYA
TAIMIR PEN
LOMONSOV RIDGE
CANADIAN
BASIN
BANKS IS
LAPTEV
SEA
EAST
SIBERIAN
SEA
CHUKCHI
SEA
ALASKA
BERING STRAIT
SIBERIA
1
2
3
4
5
6
50
100
200
500
1000
1500
2000
DEPTH IN FATHOMS

Figure 3-1. Arctic Ocean: Bathymetry

Table 3-I. Fathoms/Metres Conversion Table

C 0–499 FATHOMS TO METRES

*(The conversions below 12 fathoms are only to be used in converting depths over 500 fathoms **Table D**)

fm	0	1	2	3	4	5	6	7	8	9
0	*0	*2	*4	*5	*7	*9	*11	*13	*15	*16
10	*18	*20	22	23	25	27	29	31	33	34
20	36	38	40	42	44	46	48	49	51	53
30	55	57	59	60	62	64	66	68	69	71
40	73	75	77	79	80	82	84	86	88	90
50	91	93	95	37	99	101	102	104	106	108
60	110	112	113	115	117	119	121	123	124	126
70	128	130	132	134	135	137	139	141	143	144
80	146	148	150	152	154	155	157	159	161	163
90	165	166	168	170	172	174	176	177	179	181
100	183	185	187	188	190	192	194	196	198	199
110	201	203	205	207	208	210	212	214	216	218
120	219	221	223	225	227	229	230	232	234	236
130	238	240	241	243	245	247	249	251	252	254
140	256	258	260	262	263	265	267	269	271	272
150	274	276	278	280	282	283	285	287	289	291
160	293	294	296	298	300	302	304	305	307	309
170	311	313	315	316	318	320	322	324	326	327
180	329	331	333	335	336	338	340	342	344	346
190	347	349	351	353	355	357	358	360	362	364
200	366	368	369	371	373	375	377	379	380	382
210	384	386	388	390	391	393	395	397	399	401
220	402	404	406	408	410	411	413	415	417	419
230	421	422	424	426	428	430	432	433	435	437
240	439	441	443	444	446	448	450	452	454	455
250	457	459	461	463	465	466	468	470	472	474
260	475	477	479	481	483	485	486	488	490	492
270	494	496	497	499	501	503	505	507	508	510
280	512	514	516	518	519	521	523	525	527	529
290	530	532	534	536	538	539	541	543	545	547

fm	0	1	2	3	4	5	6	7	8	9
300	549	550	552	554	556	558	560	561	563	565
310	567	569	571	572	574	576	578	580	582	583
320	585	587	589	591	593	594	596	598	600	602
330	604	605	607	609	611	613	614	616	618	620
340	622	624	625	627	629	631	633	635	636	638
350	640	642	644	646	647	649	651	653	655	657
360	658	660	662	664	666	668	669	671	673	675
370	677	678	680	682	684	686	688	689	691	693
380	695	697	699	700	702	704	706	708	710	711
390	713	715	717	719	721	722	724	726	728	730
400	732	733	735	737	739	741	742	744	746	748
410	750	752	753	755	757	759	761	763	764	766
420	768	770	772	774	775	777	779	781	783	785
430	786	788	790	792	794	796	797	799	801	803
440	805	807	808	810	812	814	816	817	819	821
450	823	825	827	828	830	832	834	836	838	839
460	841	843	845	847	849	850	852	854	856	858
470	860	861	863	865	867	869	871	872	874	876
480	878	880	881	883	885	887	889	891	892	894
490	896	898	900	902	903	905	907	909	911	913

For soundings over 500 fm select to the nearest 100 fm below and convert to metres from table D. To this add converted depths from table C

D 500–6000 FATHOMS TO METRES

fm	m	fm	m	fm	m	fm	m
500	914	1000	1829	1500	2743	2000	3658
600	1097	1100	2012	1600	2926	3000	5486
700	1280	1200	2195	1700	3109	4000	7315
800	1463	1300	2377	1800	3292	5000	9144
900	1646	1400	2560	1900	3475	6000	10.973

Reproduction from modified British Admiralty Conversion Tables towards Greenland, with a maximum depth of about 830 fathoms (1,518 m.), while in Denmark Strait the sill depth is about 300 fathoms (549 m.).

f. Around Baffin Bay the shelf is everywhere relatively narrow and nowhere exceeds a width of 60 miles (100 km.). The shelf is widest off middle Baffin Island, Labrador, and west Greenland south of 78°N. The latter shelf contains numerous important fishing banks. Central Baffin Bay is a basin with depths exceeding 1,080 fathoms (1,975 m.). The sill across Davis Strait appears to be about 330 fathoms (604 m.) deep. Baffin Bay connects with the Arctic Ocean through a network of channels ending in three sounds, Smith, Jones and Lancaster. The Jones Sound connection is quite restricted but the channels leading to Lancaster and Smith sounds are relatively deep, the approximate sill depths being 80 – 120 fathoms (146 – 219 m.) respectively.

303. WATER MASSES

a. In the Arctic, the most important processes conditioning and modifying the ocean water are:

(1) Addition of freshwater from the land, primarily from the large Siberian rivers.

(2) Addition of freshwater locally through melting of ice.

(3) Heat gain through absorption of solar radiation in non-ice-covered areas during summer.

(4) Concentration of salt, and hence increase of density of surface water, through freezing and convective overturn.

(5) Heat loss to the atmosphere through any open water surface, including leads in the central Arctic pack ice.

b. Processes (1) to (3) lead to decreases in density of the water affected, and occur only during the short summer (June-September). Consequently in summer, the surface waters exhibit somewhat lower salt content than in winter, and in ice-free areas (e.g. parts of Baffin Bay) surface temperatures may rise to a few degrees above freezing. In ice-covered areas the temperatures remain near the freezing point because the added heat goes to melting the ice rather than warming the water.

c. Processes (4) and (5) lead to increases in density of surface water. In some areas, under certain conditions, these modified waters sink to sub-surface levels, 55 – 110 fathoms (101 – 201 m.) in depth, but in general in Arctic waters these concentration mechanisms are not adequate to create water of sufficient density to replace waters lying deeper than 110 fathoms (201 m.). Thus all Arctic deep waters are advected into and out of Arctic seas from adjacent areas. As the connection with the Pacific Ocean through Bering Strait is narrow (width about 50 miles: 75 km.), depth about 30 fathoms: 55 m.), the deeper waters of the Arctic Ocean, as well as Baffin Bay, essentially originate in the North Atlantic.

d. Similarity in vertical structure at diverse locations throughout the Arctic Ocean (Figure 3-II) reflects the common, North Atlantic origin of water deeper than 110 fathoms (201 m.) and the similarity of local processes modifying the surface water, principally the Arctic climatic factors. On the basis of temperature, three water masses may be defined:

(1) Surface water (Arctic water), from the surface down to about 110 fathoms (201 m.), which has varying characteristics. In ice-covered areas the water temperature is close to that of freezing for the salt content. In the usually ice-free areas (eastern Greenland Sea; along west Greenland north through Davis Strait) temperatures may be a few degrees above freezing. Areas that are ice-free in

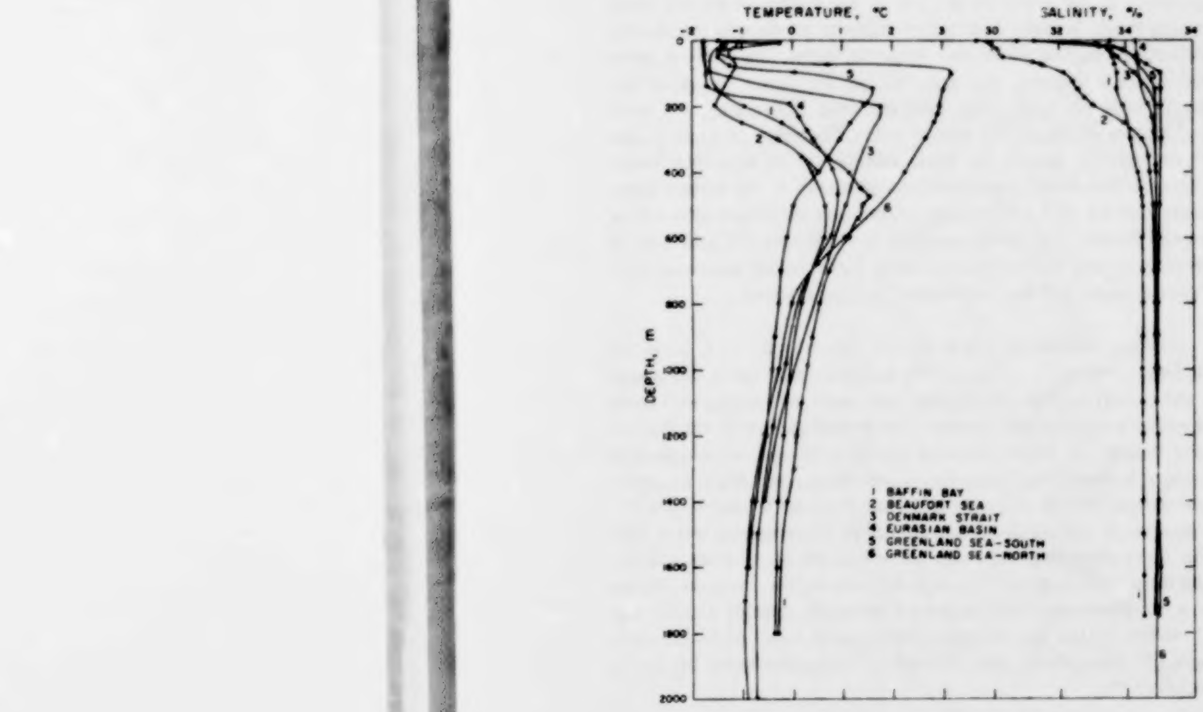


Figure 3-11. Vertical Distributions of Temperature and Salinity at Six Localities (See Figure 3-1)

summer (Chukchi Sea; nearshore areas of other peripheral seas; most of Baffin Bay) may seasonally exhibit surface temperatures of 1-2°C or more. Temperatures below the surface are typically always cold, except in the Canadian Basin of the Arctic Ocean, where there may appear a small temperature maximum (-1.0°C) in the 40 – 55 fathoms (73 – 101 m.) layer. This is attributable to influx of Bering Sea water, which is transported around the Beaufort Sea gyre (see Article 304–Currents). The salinity of the surface layer may be uniform down to about 25 fathoms (46 m.) and then increase until at 110 fathoms (201 m.) it is 34.5°/°°, or it may begin to increase closer to the surface. The surface salinity values also exhibit spatial variation (see below).

(2) The layer below the Arctic water, from about 110 – 500 fathoms (201 – 914 m.), known as the Atlantic layer, has temperatures above 0°C, with a maximum at 170 – 270 fathoms (311 – 494 m.). Salinities continue to increase over the surface values until by 220 fathoms (402 m.), and in many instances shallower depths, they attain in the Greenland Sea and Arctic Ocean nearly uniform values in the range 34.9-35.0°/₀₀, and in Baffin Bay, 34.5-34.6°/₀₀.

(3) Beneath the Atlantic layer is bottom water with temperatures below 0°C and the same uniform salinities attained in the Atlantic layer. Deep temperatures vary slightly from basin to basin; in the Canadian Basin they are about -0.5°C, in the Eurasian Basin -0.9°C, in the Greenland Sea -1.2°C, and in Baffin Bay -0.45°C.

e. All waters in the Arctic are cold, and the density of cold water is much more strongly influenced by salinity than by temperature: thus the vertical distribution of density closely parallels that of salinity. On the basis of density, the Arctic waters show a two-layer system, with a thin, less dense surface layer separated from the main body of water of quite uniform density. Vertical motion is therefore restricted, and the vertical transfer of heat and salt, and hence the surface layer acts as a "lid" over the large masses of warmer water below.

f. There is little spatial variation of surface temperature throughout the Arctic. Only those areas that are normally ice-free all year round exhibit temperatures significantly above freezing. These areas are influenced by currents carrying warmer water into the Arctic (eastern Greenland Sea – West Spitsbergen Current, and the northward flowing current along west Greenland), and remain ice-free for that reason. Seasonal temperature fluctuations occur in areas that are typically ice-free seasonally (July-September) and include the coastal sectors of the peripheral seas of the Arctic Ocean, north of Bering Strait, and around eastern and northern Baffin Bay. Areas in which major currents carry Arctic water towards the North Atlantic (western Baffin Bay – Canadian Current; western Greenland Sea – East Greenland Current) remain ice-covered for longer periods and have temperatures close to freezing at all times.

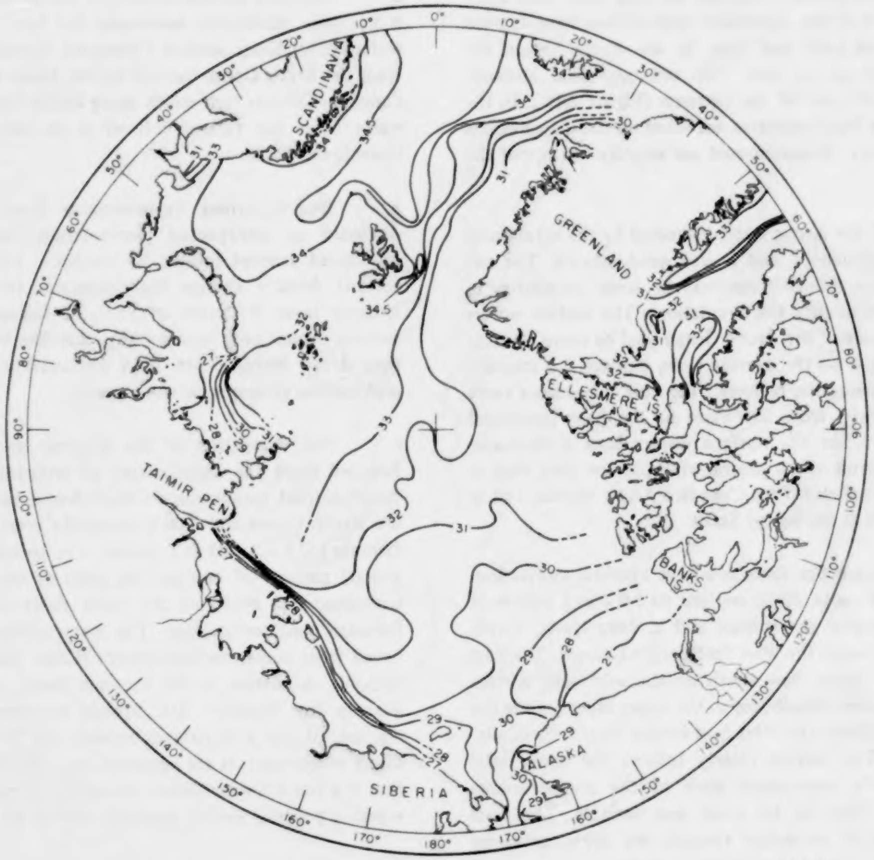
g. In nearly closed basins in higher latitudes (e.g. Arctic Ocean, Baffin Bay) there is a surface outflow of relatively fresh water with some saline water entrained with it, and an inflow of more saline water at depth to maintain the salt balance. In such basins there is an increase in surface salinities from the head of the basin, close to the source of freshwater, towards the mouth, owing to progressive mixing between the surface layer and the underlying more saline water.

h. The general conditions for basins in high latitudes are fulfilled by the Arctic Ocean and Baffin Bay (Figure 3-III). The surface salinity in summer is lowest along the periphery of the Arctic Ocean from the Mackenzie River delta to the Kara Sea, because major rivers discharge throughout this area. Salinities are never much below about 27°/oo, except very close to a river mouth, because the freshwater is efficiently mixed with more saline deeper water on the shallow continental shelf by the action of winds, tides and currents. Salinities in general increase progressively in the direction of flow of the surface water and attain maximum values in those areas where currents are directly introducing North Atlantic surface water into the Arctic basins. The North Atlantic surface water is heavier, and sinks within the basins to sub-surface levels. Though no large rivers discharge into Baffin Bay, the same general picture of the surface salinity holds. The influx of Arctic Ocean water through the sounds has lower salinity due to local melt water, and hence is less dense and contributes primarily to the surface layer. Intensive melting of ice in summer contributes significant amounts of freshwater locally, and hence relatively low salinities (31°/oo) may be observed in central Baffin Bay and along Baffin Island associated with the "central pack" and the outflowing Canadian Current.

i. Surface salinities in winter can be higher by 0.5 – 1°/oo in the Arctic Ocean and by 1 – 2°/oo in the peripheral seas, for at this season melt and run-off are not contributing freshwater, but mixing with more saline waters is continuous. However, the general pattern of distribution remains similar. In winter (October-April), a process of considerable importance in modifying the surface waters takes place. When ice grows from seawater, the salt is largely excluded from the ice and results in a local increase in salinity and hence density of the remaining water. This process takes place over the entire surface of the Arctic areas, and the average ice growth is about 5 ft. (1.5 m.) each winter. However, the ice cover is not continuous and leads are continually opening and closing. The heat loss to the atmosphere from the open water of leads occurs perhaps 100 times faster than through ice (also producing fog in the atmosphere).

304. CURRENTS

a. The surface circulation has been largely derived from the observed drift of manned ice islands, floe stations, and ships. Current measurements have shown that on the average the drifting stations and the surface water tend to move in similar directions at similar speeds,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SCANDINAVIA
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ELLESMERE IS
BANKS IS
ALASKA
SIBERIA
TAIMIR PEN
34.5
34
33
32
31
30
29
28
27
26

Figure 3-III. Mean Surface Salinity – Summer (parts per thousand)

though there may be considerable variations between them over short periods. Indirect estimates of the circulation pattern have been derived from the distributions of mass and heat. In the Arctic Ocean the dynamic topography, based on over 300 oceanographic stations, provides a quantitative estimate of the currents (Figure 3-IV). In the Greenland Sea and Baffin Bay, estimates are based on the distributions of temperature and salinity. Superimposed are velocity vectors of the drift of selected stations.

b. The circulation of the Arctic water is created by the rotation of the earth, by density differences, and is also wind-induced. The net effect of tides is unknown though there may be some asymmetry in their action, which would modify the circulations. The surface waters from the whole Eurasian side of the Arctic Ocean tend to move towards the North Pole. This flow is on the average slow, perhaps 2-3 cm./sec. (.04-.06 kt.), but after passing the region of the Pole it becomes more concentrated and then exits from the basin as the East Greenland Current. In the Beaufort Sea the surface waters have a clockwise movement, apparently a result of the general wind pattern; they tend to flow to the west along the shelf off the Canadian Arctic Islands, and to the north in the area north of the Bering Strait.

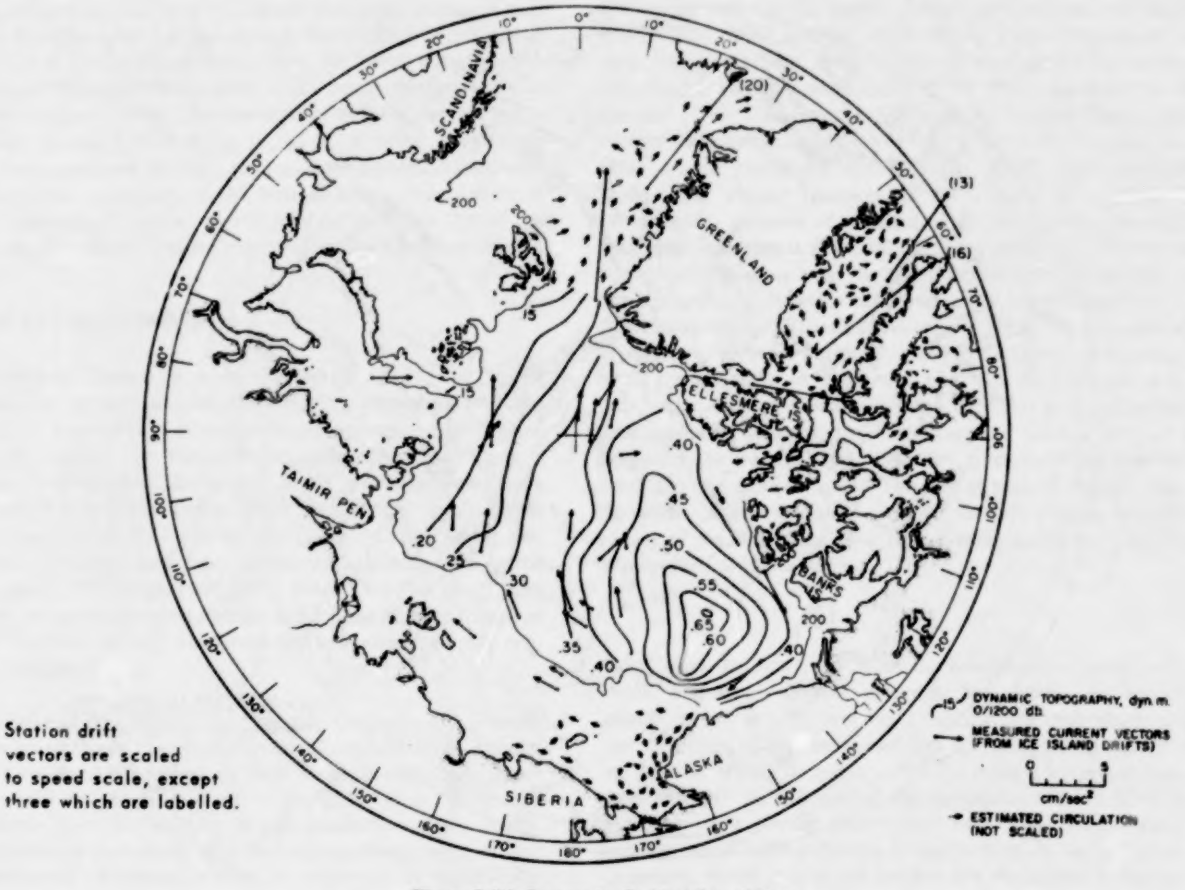
c. Around the Greenland Sea there is a large cyclonic circulation, with average speeds in the range 10-20 cm./sec. (0.2-0.4 kt.). Inflow of North Atlantic water, both at the surface and at deep levels, occurs along the east side of the sea as the West Spitsbergen Current. The East Greenland Current is the major flow south on the west side; surface water from the Arctic Ocean contributes to the upper layers, while the deeper waters are largely from the West Spitsbergen Current, completing the cyclonic gyre. The current closely follows the continental slope, and over the wide continental shelf of the northern area (77-80°N) the currents tend to be weak and variable. The East Greenland Current seems to accelerate towards the south, attaining speeds of 15-40 cm./sec. (0.3-0.8 kt.) near Denmark Strait.

d. The same general pattern of circulation is found in Baffin Bay. A cyclonic circulation dominates the bay; inflow of North Atlantic water occurs along western Greenland through Davis Strait, and inflow from the Arctic Ocean through Smith, Jones and Lancaster sounds. The Canadian Current runs south along Baffin Island, and as it accumulates water from the various inflows it in general shows higher speeds towards the south.

e. Direct current measurements from ice island T-3 in 1965 disclosed an unexpected phenomenon, consisting of a "core" of high-speed current (about 50 cm./sec.: 1.0 kt.) located in a major vertical density change that separates the Arctic water from the Atlantic layer at depths of 55 – 85 fathoms (101 – 155 m.). This motion occurs only occasionally, and has been observed to grow and then decay within a few days. Presumably this motion is associated with certain atmospheric phenomena.

f. The circulation of the Atlantic layer (Figure 3-V) has been deduced from the distributions of temperature and salinity. Recent direct current measurements from Soviet and U.S. drifting stations in the Arctic Ocean and East Greenland Current in this layer 170 – 550 fathoms (311 – 1,005 m.), shown as vectors in Figure 3-V, confirm the general pattern of motion. On entering the Eurasian basin from the Greenland Sea much of the water flows east along the edge of the Eurasian continental slope. The water enters the Canadian Basin on a broad front across the Lomonosov Ridge. There appears to be a general cyclonic circulation in the Eurasian Basin, and a smaller anticyclonic gyre in the Beaufort Sea. Speeds are everywhere low, less than 5 cm./sec. (0.1 kt.). Variations between the "mean" flow pattern and the direct measurements are apparent, but observations are as yet so sparse that it is not known whether the deduced "mean" pattern is in error, or whether periodic and/or aperiodic effects are significant in the motion.

g. Direct current measurements in the Atlantic layer of the


SCANDINAVIA
GREENLAND
ELLESMERE
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TAIMIR PEN
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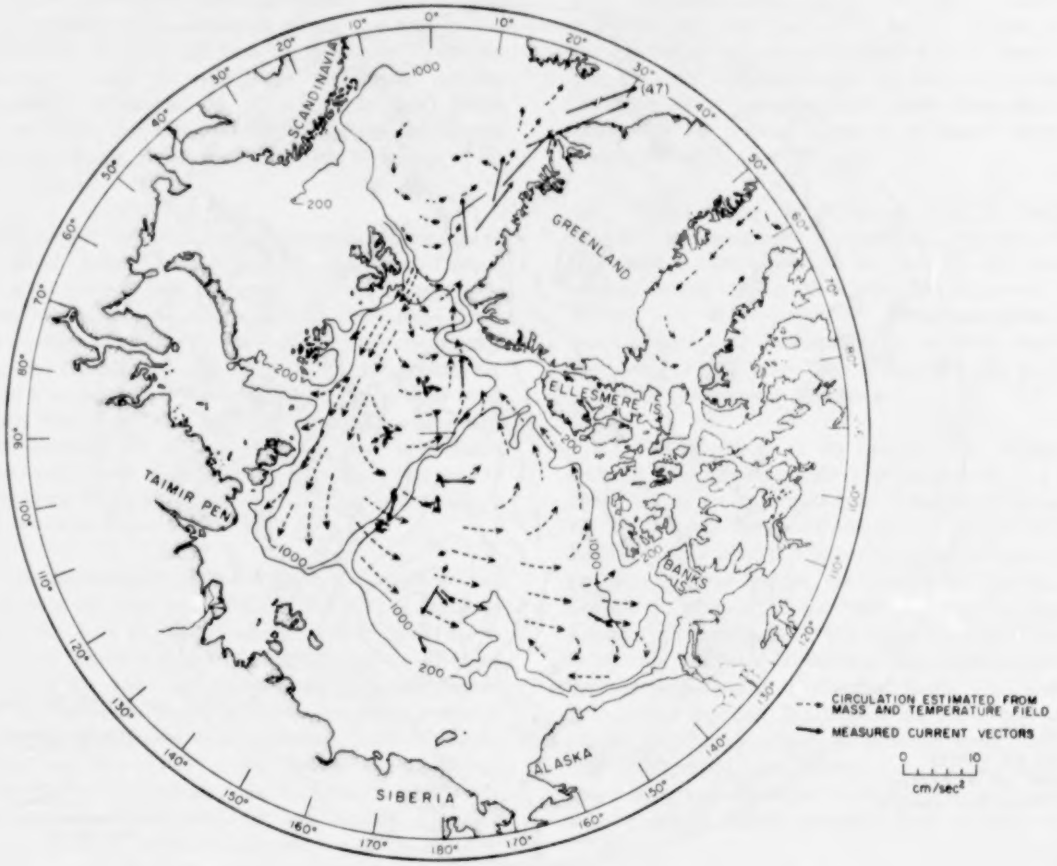
100°
110°
120°
130°
140°
150°
160°
170°
180°
15 DYNAMIC TOPOGRAPHY, dyn.m. 0/1200 db
MEASURED CURRENT VECTORS (FROM ICE ISLAND DRIFTS)
0
5
cm/sec²
ESTIMATED CIRCULATION (NOT SCALED)

Station drift
vectors are scaled
to speed scale, except
three which are labelled.

Figure 3-IV. Composite Surface Circulation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130°
140°
150°
160°
170°
180°
SCANDINAVIA
GREENLAND
ELLESMERE
TAIMIR PEN
BANKS
SIBERIA
ALASKA
1000
200
(47)
CIRCULATION ESTIMATED FROM MASS AND TEMPERATURE FIELD
MEASURED CURRENT VECTORS
0
10
cm/sec²

Figure 3-V. Composite Atlantic Layer Circulation

East Greenland Current show there is little variation in velocity with depth. Thus the deep motion is similar to that of the surface water. Deductions from the mass and temperature fields indicate a circulation similar to that of the Greenland Sea (without the loss of water into the Arctic Ocean). The speeds presumably would be of the same order as those of the surface currents. Measurements of bottom currents in the Arctic Ocean, in over 1,500 fathoms (2,743 m.) of water, gave results similar in both speed and direction to that of the Atlantic layer above. Thus, though the circulation of the bottom Arctic Ocean water is essentially unknown, it appears that it may be similar to that of the Atlantic layer. The same statement may hold for the Greenland Sea and Baffin Bay.

305. ADVECTION BOUNDARIES

a. Boundaries between the Arctic seas and the Atlantic and Pacific, and between the Arctic Ocean and Baffin Bay, are of prime importance because of the major role of advection in determining the characteristics of Arctic waters. The best known oceanographically of these is Bering Strait, through which, in summer, Bering Sea surface water flows north into the Arctic Ocean. In the eastern channel of the strait, speeds normally range between 50 – 100 cm./sec. (1-2 kt.) though speeds over 150 cm./sec. (2.9 kts.) have been measured. Speeds are less in the western channel. The volume transport is about 1 x 10^6 m.^{3} sec.$^{-1}$. The situation in winter is unknown, though it has been suggested that the northward flow may be only one-fourth that of summer, and may even reverse on occasion.

b. The general flow through the Canadian Archipelago is apparently from the Arctic Ocean towards Baffin Bay. Recent documentation of the drift of ice island WH-5 through Nares Strait (connecting to Smith Sound) confirms the general flow out of the Arctic Ocean through this strait. However, there was evidence of large pulsations in the southerly flow; the indicated periodicity of a few days to weeks suggests that major atmospheric disturbances may be important in significantly altering the flows through these channels.

c. The strait between Greenland and Svalbard provides the primary connection between the waters of the North Atlantic and the Arctic Ocean; water flows into the Arctic Ocean on the eastern side of the strait and out of the Arctic Ocean on the western side as the East Greenland Current. A new concept of the circulation in the Greenland Sea and of the East Greenland Current has resulted from analysis of current measurements made from ice island Arlis-II during its drift along eastern Greenland during winter, 1965. The measurements showed the volume transport of the current to be about 40 x 10^6 m.^{3} sec.$^{-1}$, an order of magnitude larger than previously estimated. This large transport is apparently a major circulation internal to the Greenland-Norwegian seas; the outflow and inflow from the Arctic Ocean represent only minor contributions and subtractions from a large cyclonic circulation. The Arctic water portion of the current to a large extent controls the ice distribution, and so its presence is significant out of all proportion to its small contribution to the total transport. The flow pattern in Denmark Strait is similar to that in the strait between Greenland and Svalbard; the East Greenland Current flowing south dominates the western side, and a flow from the North Atlantic runs north and east around Iceland. The East Greenland Current, transporting polar ice south, usually occupies three-fourths or more of the surface of the strait. The flow regime varies seasonally, with summer usually the time of minimum ice.

d. One important aspect of the oceanographic structures of the Arctic seas is the layered nature of the waters. The Arctic water effectively lies as a lid over the Atlantic water underneath: although vast quantities of heat are carried into the Arctic Ocean and Baffin Bay by Atlantic water, its influence on the surface layers and hence the possibility of its influencing the environment are limited by the extremely slow vertical transport of heat. The Atlantic water does exercise considerable influence in the Norwegian Sea and along West Greenland, where it is at the surface and the surface is exposed. The Atlantic water also exerts some influences on ice cover and climate in the seas bordering Siberia. It enters these seas along submarine canyons, particularly in the Kara Sea, where it works its way up to shallower depths. Through a more pronounced influence of tidal action in the shallower water and the vigorous development of vertical convection in winter, the heat of the Atlantic water is carried to the surface where it is apparently responsible for areas of much thinner ice cover and even for semi-permanent areas of open water (polynyas). A similar effect occurs in northern Baffin Bay, where an area of perhaps 7,700 sq. miles (20,000 sq. km.) of Smith Sound has typically very thin ice or even open water all winter ("North Water"). The cause of the "North Water" is unknown, though clearly some source of warmer water near the surface, as with the Siberian polynyas, is required for its existence. In general, within the deep-water part of the Arctic seas, the warm Atlantic layer has negligible influence on climate.

SECTION II – REGIONAL OCEANOGRAPHY

306. INTRODUCTION

a. The oceanography of the peripheral Arctic seas and the polar basin is presented in this Section. Emphasis has been placed on a detailed consideration of the oceanography of the western and eastern approaches to the Polar Basin, from the Bering Strait, the Davis Strait and the Greenland and Norwegian Seas.

b. The appropriate Sailing Directions, Charts and Oceanographic Atlases should supplement this Section.

307. THE SEA OF OKHOTSK

a. The Sea of Okhotsk is produced where the continent of Asia is separated from the Pacific Ocean by Kurilskiye Ostrova (Kuril Islands) and the Kamchatka Peninsula. The western boundary south of 54°N is formed by the island of Sakhalin, and the southern by the Japanese island of Hokkaido.

b. The west coast of the Kamchatka Peninsula is much like the east in its northern sector, but from about 59°N it is bordered by a coastal lowland with widths up to 50 miles(80 km.). The marshy coastal plains are fringed in the central and southern sections by lagoons and offshore sand and gravel bars.

c. O. Kurilskiye run in a narrow concave arc along the southern boundary of the sea. They are part of the Pacific volcanic arc which extends from the Aleutians through Kamchatka, the Kuril Islands and Japan; there are over 100 cones in the island chain, of which 38 are active. Kamchatka Peninsula, more than 700 miles (1,100 km.) long, separates the Sea of Okhotsk from the Bering Sea and the northwest Pacific Ocean. Forty volcanoes are known, almost all on the eastern side of the peninsula; fourteen are active. The highest almost reaches 16,000 ft. (4755 m.) and many exceed 10,000 ft. (2926 m.).

d. The island of Sakhalin is over 590 miles (950 km.) long and is separated from the mainland by the Strait of Tartary. Two mountain ranges, an eastern and a western, dominate the relief of the island; both subside in the north leaving an extensive lowland with elevations up to 2,343 ft. (708 m.) at Cape Yelizaveta. The eastern range is higher than the west, reaching heights in the centre of 6,600 ft. (3,015 m.). Between the ranges a central lowland runs northward from Terpeniya Gulf, where it forms a coastal plain. Apart from this the coasts of southeast Sakhalin are relatively steep and rocky.

e. *Bathymetry.* Depths in the Sea of Okhotsk range from a shelf under 100 fathoms (183 m.) in the north to over 1800 fathoms (3292 m.) near the Kuril arc, but here the slope between the two is gradual except off the east coast of Sakhalin, where it is fairly steep (Figure 3-VI).

f. *Currents.* The general circulation in the Sea of Okhotsk is counterclockwise, and runs strongest 20 – 40 miles (30-60 km.) offshore. A complex pattern of currents has been reported from the middle of the sea (Figure 3-VI). The current moves north along western Kamchatka at 0.5 kt.; in other sectors velocities up to 1 kt. are recorded. The Sea of Okhotsk has one unusual feature which affects both the ice conditions and the climate. This is the patches of substantially colder water (1 – 6°C) that are located at the entrance of Penzhinskiy Gulf in the northeast, off Iony Island, and between the Shantar Islands and northern Sakhalin. These cold spots mark upwellings of colder deeper water, the cause of which is still in doubt. They are associated with continuous dense fogs in the summer and concentrations of ice in the winter. The exchange of water with the Pacific Ocean is not great, due to the shallow depths (usually less than 260 fathoms: 475 m.) of the channels between the Kuril Islands. Pacific waters normally enter through the northeastern channels, and Okhotsk water leaves by the southwestern channels.

308. THE BERING SEA AND THE BERING STRAIT

a. *General.* The Bering Sea is the northernmost marginal sea of the Pacific Ocean. It is bounded on the north by the Siberian and Alaskan land masses and on the south by the Aleutian Island arc. Its area is 890,000 square miles (2.3 million sq. km.). Bering Strait, 50 n.m. (93 km.) wide, separates the Eurasian and American continents and connects the Bering and Chukchi Seas.

b. *Bathymetry*

(1) A steep continental slope traverses the Bering Sea from southeast to northwest and divides it into two distinct and approximately equal parts. The southwestern half is an abyssal oceanic basin with depths greater than 2000 fathoms (3658 m.). Two submarine ridges penetrate the basin: one extends in a counterclockwise arc northward from the Aleutian chain at 179°W; the other southward from Mys Olyutorskiy along 170°E. The northeastern half of the Bering Sea is an extensive, flat, and shallow continental shelf averaging about 30 fathoms (55 m.) in depth. The shelf continues north through Bering Strait and underlies the Chukchi Sea, the whole constituting the Bering-Chukchi platform. Its shallow depth restricts the exchange of water between the Bering Sea and the Arctic Basin to the surface layers.

(2) In the central and eastern portion of the Aleutian arc the passages between the islands are shallow and limit the exchange of Pacific and Bering Sea water to the upper layers. The passages westward of the Near Islands (173°E) are deeper, reaching a maximum depth of 2417 fathoms (4420 m.) between the Komandorskiy Islands and Kamchatka. (Figure 3-VII.)

c. *Currents*

(1) The overall circulation in the Bering Sea basin is cyclonic (counterclockwise) (see Figure 3-VIII), velocities being in general less than 0.5 kt. Alaskan Stream water flowing westward along the south of the Aleutians converges with western Pacific sub-Arctic water and enters the Bering Sea west of Attu. The main current moves northeastward and then eastward along the north side of the Aleutians, mixing with Pacific near-surface water that has entered the Bering Sea through the island passages. The flow turns northward at the continental shelf and follows the continental slope to south of Mys Navarin. There the stream diverges, part setting southwestward along the Siberian coast and returning to the Pacific between the Komandorskiy Islands and Kamchatka as the East Kamchatka Current, and part going north through Bering Strait. Smaller circulations are superimposed on this general cyclonic pattern.

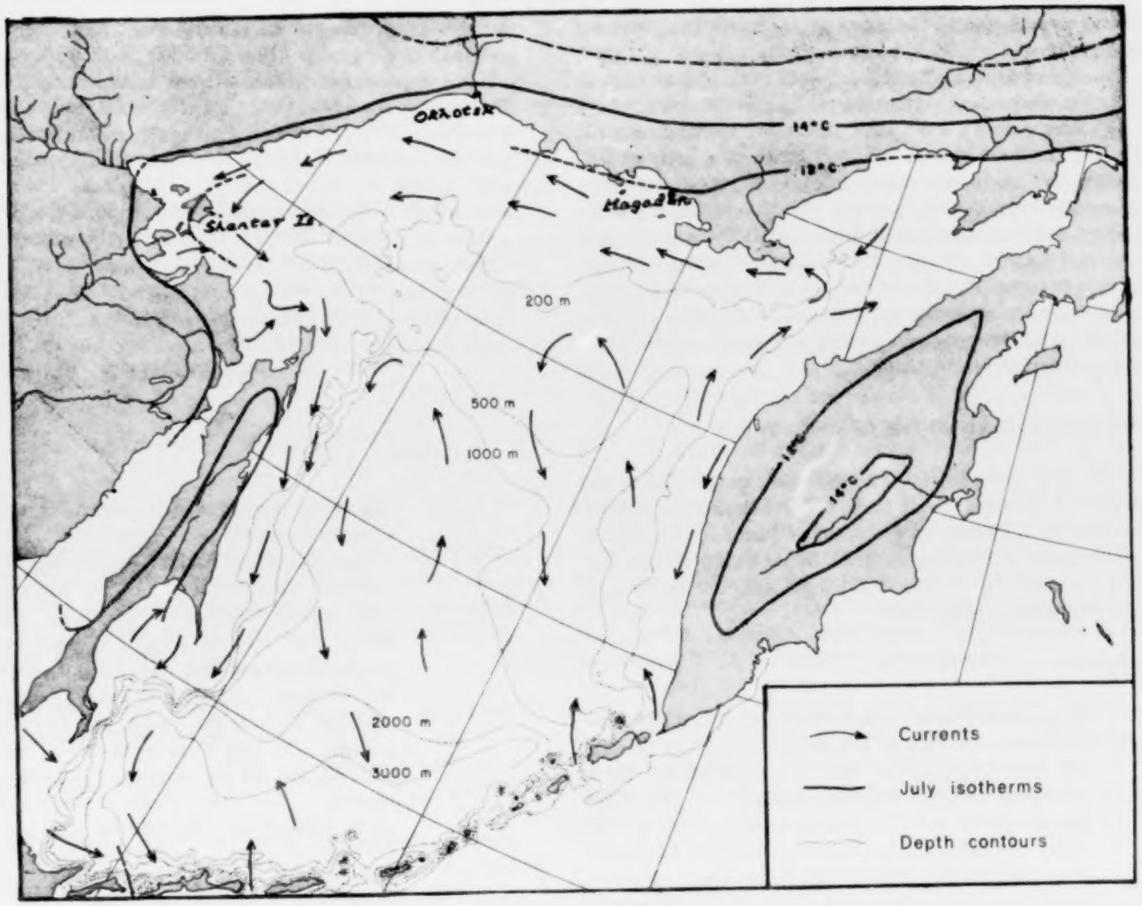

Okhotsk
Magadan
Shantar Is.
14°C
13°C
14°C
200 m
500 m
1000 m
2000 m
3000 m
Currents
July isotherms
Depth contours

Figure 3-VI. Sea of Okhotsk – Bathymetry, Surface Currents and July Mean Temperatures

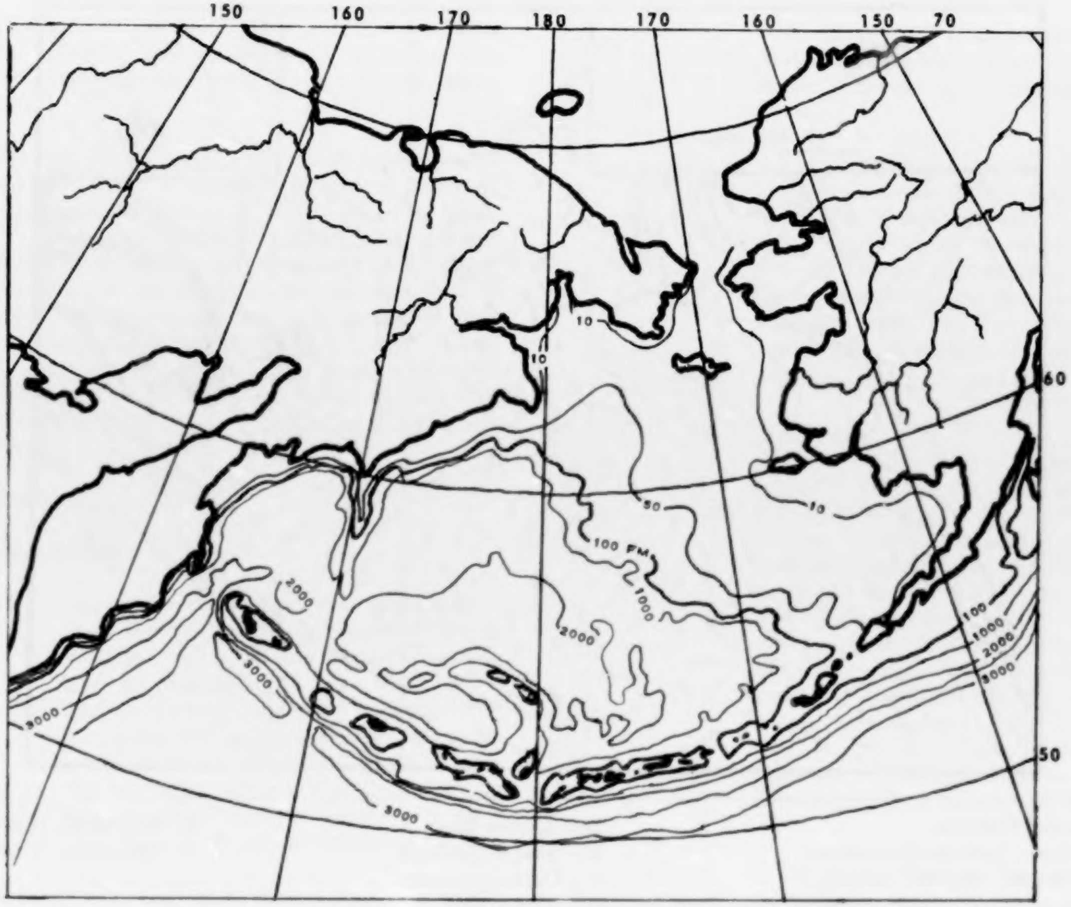
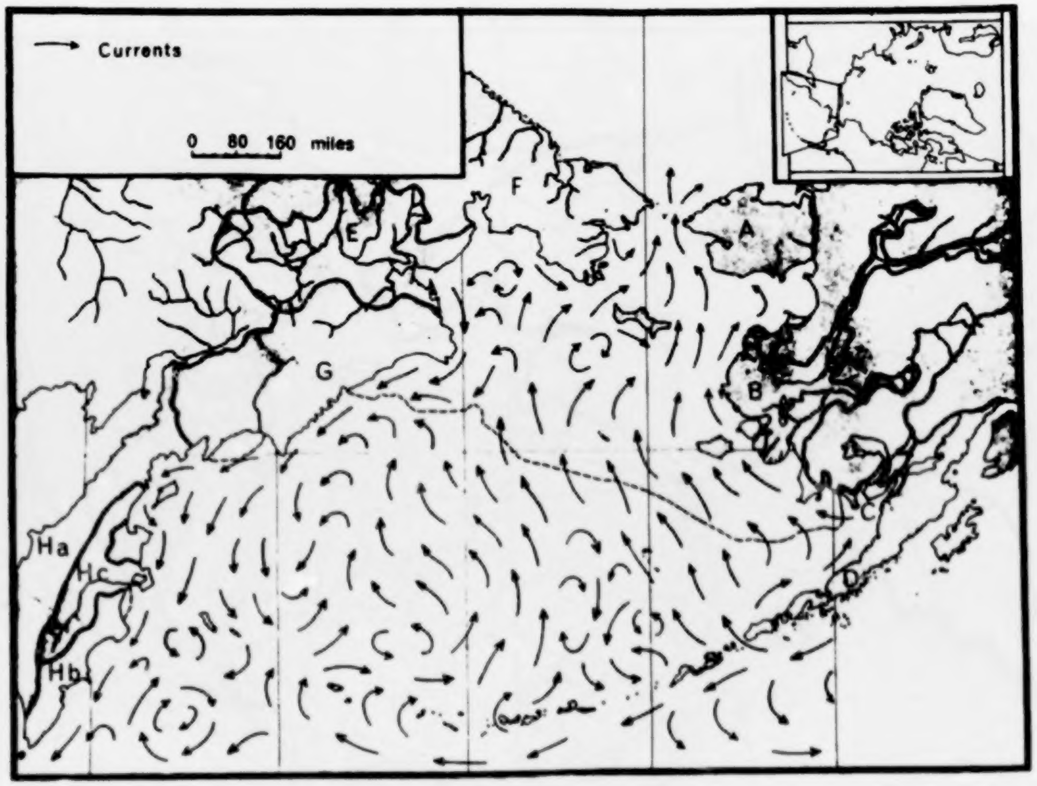

150
160
170
180
170
160
150
70
60
50
10
10
10
10
50
100 FM
1000
2000
2000
3000
3000
3000
100
1000
2000
3000

Figure 3-VII. Bathymetry of the Bering Sea


Currents
0 80 160 miles
A
B
C
D
E
F
G
Ha
Hb
Hc

A – Seward Peninsula
B – Yukon – Kuskokwim Lowlands
C – Nushagak – Kvichak Lowlands
D – Aleutian Range
E – Anadyr' Lowlands
F – Chukchi Peninsula
G – Koryakskiy Highlands
H – Kamchatka Peninsula

Figure 3-VIII. Bering Sea: Currents and Physiographic Regions

(2) Currents in the shallow northeastern half of the Bering Sea are mostly tidal, but discharge from Alaskan rivers sets northward along the coast and through Bering Strait.

(3) The flow through Bering Strait is predominantly northward, although a south-setting counter current is occasionally observed on the western side of the Strait. On the eastern side velocities are as high as 4 kts. (2.1 m./sec.) in summer. The flow at all depths is northward but speeds at the surface in summer exceed those at depth. The flow in August and September is 3 to 4 times as great as in winter when ice is present. Average transport over the year into the Arctic is about 42 million cubic ft. per second (1.2 million m.³/sec.). This constitutes about 20% of the total inflow into the Arctic basin.

d. *Water Structure*

(1) *Deep Bering Sea*

(a) The water in the Aleutian Basin, having entered from the Pacific, has the characteristics of Pacific sub-Arctic water. The main feature is a surface layer of comparatively low salinity (32.9° – 33.2°/oo) about 80 fathoms (140m.) deep overlying a halocline (salinity gradient) within which salinity increases to about 33.8°/oo at 120 to 200 fathoms (219m. – 366m.) depth. Below the halocline salinity increases more slowly to about 34.67°/oo at 2000 fathoms (3658 m.).

(b) The temperature structure of the surface layer is determined by surface effects – heating, cooling, wind mixing – and varies in a seasonal cycle. The positive density gradient in the halocline prevents surface influences from penetrating it to any extent.

(c) A thermocline begins to form in April and attains its maximum development in August. The depth of the top of the thermocline (i.e., the layer depth) reaches about 20 fathoms (36 m.) in June, with little further deepening until the end of the heating season in September. The layer depth of course may vary widely about its average value in response to changing weather conditions.

(d) After mid-September the surface cools and convective overturning and wave action drive the thermocline down and decrease its magnitude. By late winter (earlier farther north) it has disappeared and the water above the halocline is thoroughly mixed and isothermal. In the Bering Sea cooling continues until the homogeneous surface layer is colder than the denser water in the underlying halocline. The remnant of this cooling is evident through the summer as a temperature minimum – the "dichothermal" water – at 50 to 100 fathoms (91 – 183 m.) depth and a temperature maximum at about 170 fathoms (311 m.) in the halocline. (Figure 3-IX.)

(e) In the vicinity of the Aleutians tidal turbulence in the island passages much modifies the stratified structure of the Aleutian basin.

(f) Mean sea surface temperature in February ranges from about 30°F (–1°C) around the northern rim of the unfrozen Bering Sea to 39°F (4°C) in the central and eastern Aleutians. (See Figure 3-X.) In summer surface temperatures average 50° – 52°F (10° – 11°C) over most of the basin, but are 2° – 4°F (1° – 2°C) lower in the Kamchatka Current and 1° – 2°F (1°C) lower near the Aleutians. (Figure 3-XI.)

(2) *Continental Shelf*

(a) Temperatures below the winter ice pack are isothermal at about 29°F (–1.6°C) and isohaline at 31.8°–32.4°/oo all the way to the bottom. In spring and summer run-off dilutes the water over the shelf and a shallow thermocline forms above which salinities are lower than below it, ranging from 22.0 to 32.8°/oo. Discharge from the Yukon River is the principal contributor to the lower salinity on the east side of Bering Strait as compared with the west side.

(b) Surface temperatures vary from about 29°F (–1.6°C) in the pack ice in winter and spring to about 50°F (10°C) near the Alaskan coast and on the eastern side of Bering Strait in August. On the western side of Bering Strait in summer, surface temperature is about 44°F (7°C).

e. *Acoustic Propagation*

(1) The dichothermal temperature minimum in the Aleutian Basin constitutes through most of the year a well developed sound channel whose axis is at about 80 fathoms (146 m.) depth. Near the Aleutians the sound channel is less well defined, on its lower side especially, because turbulent mixing disturbs the stratified structure.

(2) Ambient noise is generally low and sonar ranges in the sound channel may be great.

(3) In winter a surface duct is present above the level of downward penetration of convection and mixing. Propagation conditions in the surface layer in summer will be subject to the usual weather controls, being in general poor during periods of light winds and prolonged sunshine, and improving after the water above the thermocline has been well mixed by wind action and/or surface cooling.

(4) Sound propagation over the shelf will vary markedly with season. Under the ice field it can be expected to be good, with the shallow isothermal water between the ice and the flat, featureless, mostly sandy bottom forming an efficient duct.

(5) In summer the shallow thermocline over the shelf and the large horizontal and vertical variations in temperature and salinity, especially inshore, should give very variable propagation conditions.

309. THE CHUKCHI SEA

a. *General.* The Chukchi Sea is that portion of the Arctic Ocean lying immediately north of Bering Strait. It is bounded on the west by Wrangel Island, on the north by the edge of the continental shelf, and on the east by Point Barrow (see Figure 3-XII). Its area is 225,000 square miles (582,000 sq. km.). It is sometimes referred to by its Russian name, Chukotsk Sea.

b. *Bathymetry*

(1) The Chukchi Sea is everywhere underlain by the continental shelf. Depths for the most part are between 20 and 35 fathoms (36 and 64m.) with shallower water in Kolychin Bay, Kotzebue Sound, and extending 25-50 miles (50-100 km.) from the Alaskan shore.

(2) Two submarine canyons cross the shelf. Barrow Canyon runs northeast from about 80 miles (150 km.) west of Point Barrow to debouch into the Beaufort Sea north of Point Barrow. Herald Canyon runs northward along 175°W from 70°N to the edge of the continental shelf.

c. *Currents*

(1) The circulation in the Chukchi Sea (see Figure 3-XIII) is broadly cyclonic (counterclockwise). Warm water enters through the eastern side of Bering Strait throughout the year. In July and August the surface temperature of this stream may be 50°F (10°C), with salinity less than 30°/oo due to run-off from the Yukon River south of Bering Strait. The current divides near Point Hope. One portion continues northeastwards towards Point Barrow where it turns westward and joins the general Arctic Basin circulation. The other portion branches northwestwards from Point Hope to pass north of Wrangel Island. A cold current sets southeastward from the East Bering Sea along the Siberian coast towards Bering Strait. It usually turns north before reaching the Strait, but exceptionally may flow southward through the Strait on its western side.

(2) These are average currents. At any given time the movement of surface water is largely determined by the wind.

d. *Water Structure*

(1) The water mass in the eastern Chukchi Sea is largely Bering Sea water that has entered through Bering Strait. In summer surface salinity is less than 30°/oo and temperature 45°–50°F (7°–10°C) to north of Point Hope (Figure 3-XIV), with warmer and less saline water in Kotzebue Sound.

(2) A weak thermocline is present in summer just north of the Strait, with slightly more saline water below it. Farther to the north, but south of the pack ice, the summer thermocline is more marked, with layer depths 5-10 fathoms (9-18 m.). Away from the areas cleared of ice by the warm Bering Sea water, this structure is considerably modified by melting and freezing processes. This implies that the distribution of temperature and salinity depends on the pack ice limits. Melting produces a cold low salinity layer overlying the warmer, comparatively saline, Bering Sea water. Cold, more saline bottom water resulting from winter freezing at the surface has also been noted, especially over the northern continental shelf. The warm layer of Bering Sea water intruding from the south is a characteristic feature of the Chukchi Sea. In the vicinity of the pack ice the salinity and temperature layering can be quite complex and vary considerably over comparatively short horizontal distances.

(3) The cold flow of water along the Siberian coast towards Bering Strait contrasts with the warmer, more saline water to the east. August surface temperatures in this flow range from about 32°F (0°C) at the western edge of the Chukchi Sea, to 43°F (6°C) off Mys Dezhneva. Salinity is low, less than 29°/oo, and sometimes much lower, due to discharge from the Siberian rivers.

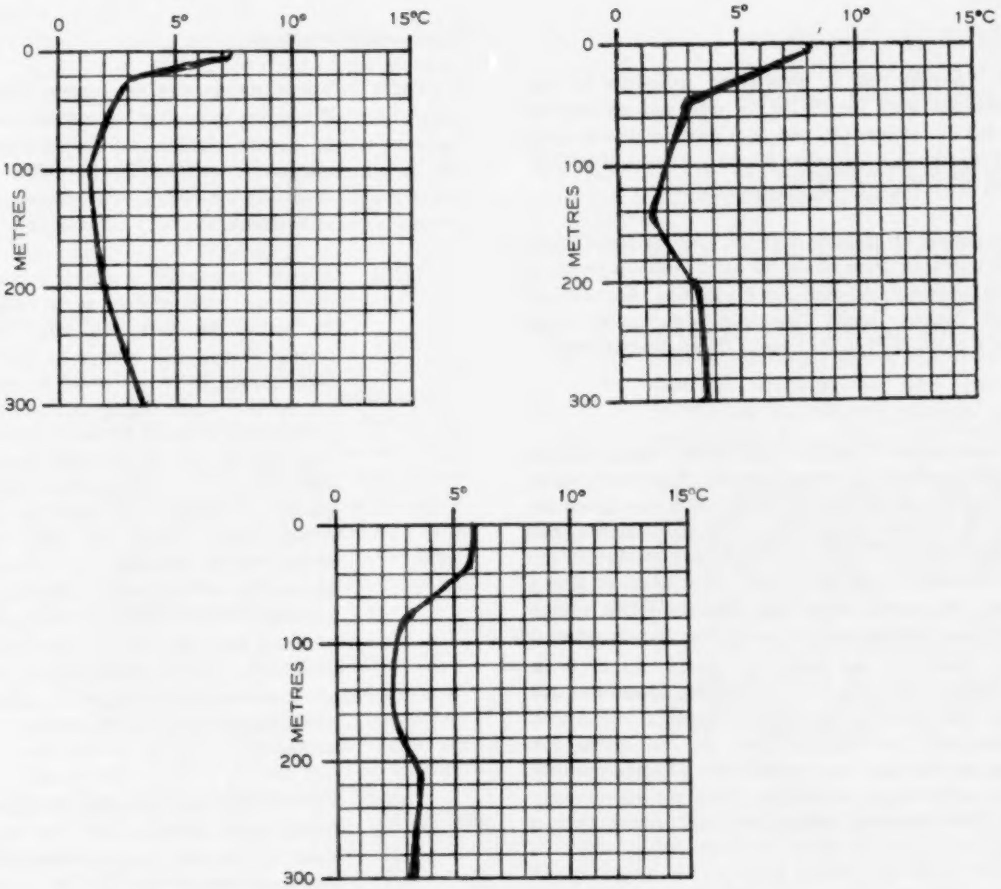


Figure 3-IX. Bathythermograph Samples in the Bering Sea, North of the Aleutians - Summer Conditions

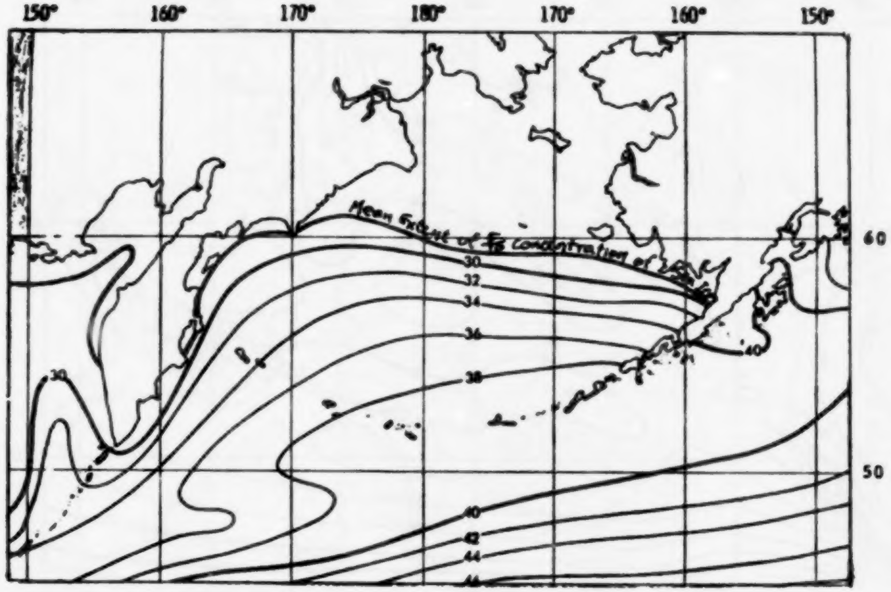

150°
160°
170°
180°
170°
160°
150°
60
50
Mean Extent of 5/8 concentration of
30
32
34
36
38
40
42
44
46
30
40

Figure 3-X. Bering Sea Surface Temperature – February (°F)

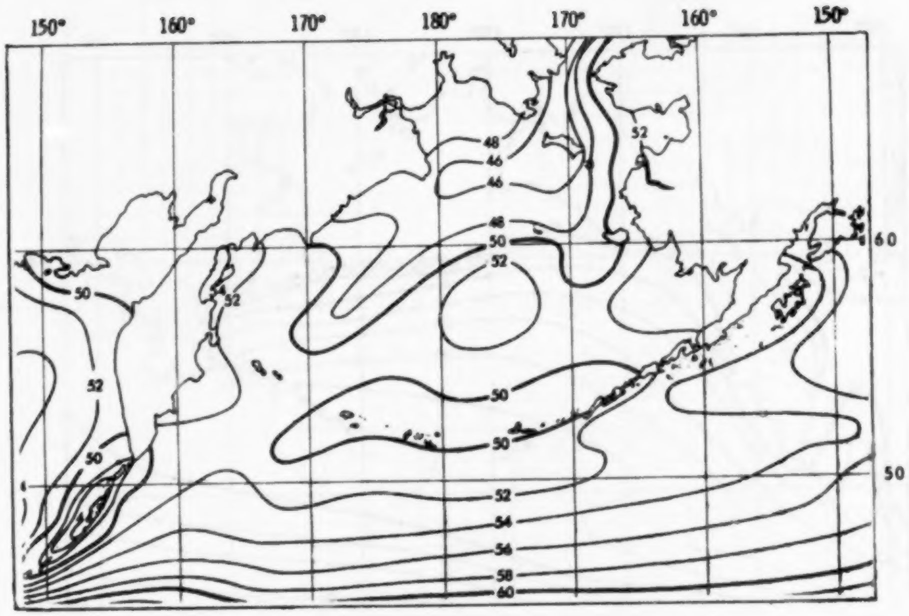
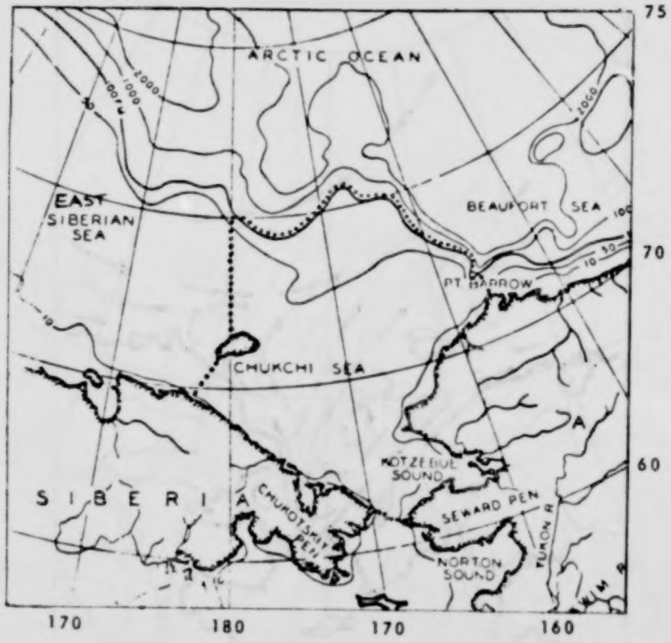

150°
160°
170°
180°
170°
160°
150°
60
50
48
46
46
48
50
52
52
50
52
52
50
50
50
52
54
56
58
60

Figure 3-XI. Bering Sea Surface Temperature – August (°F)


ARCTIC OCEAN
2000
1000
2000
2000
EAST SIBERIAN SEA
BEAUFORT SEA
100
50
10
10
PT. BARROW
CHUKCHI SEA
A
KOTZEBUE SOUND
SIBERIA
CHUKOTSKIY PEN
SEWARD PEN
YUKON R
NORTON SOUND
75
70
60
170
180
170
160

(Dotted line is boundary of Chukchi Sea.)

Figure 3-XII. Bathymetry of Chukchi Sea

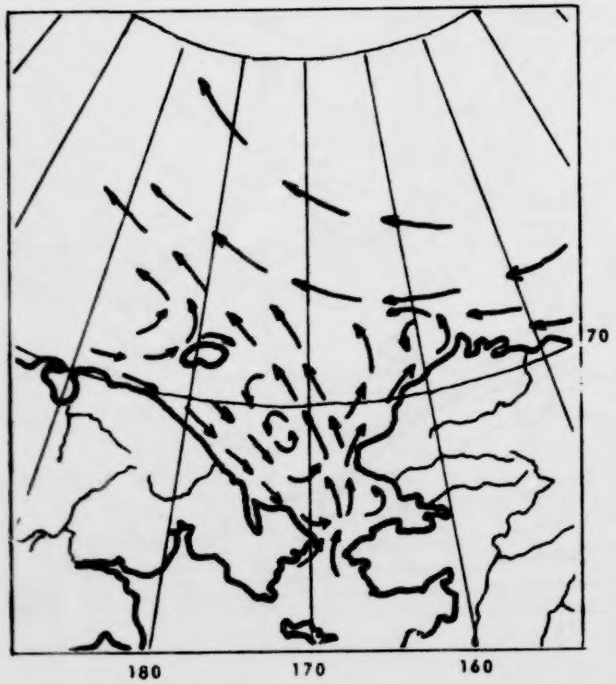

70
180
170
160

Figure 3-XIII. Chukchi Sea – Average Surface Currents

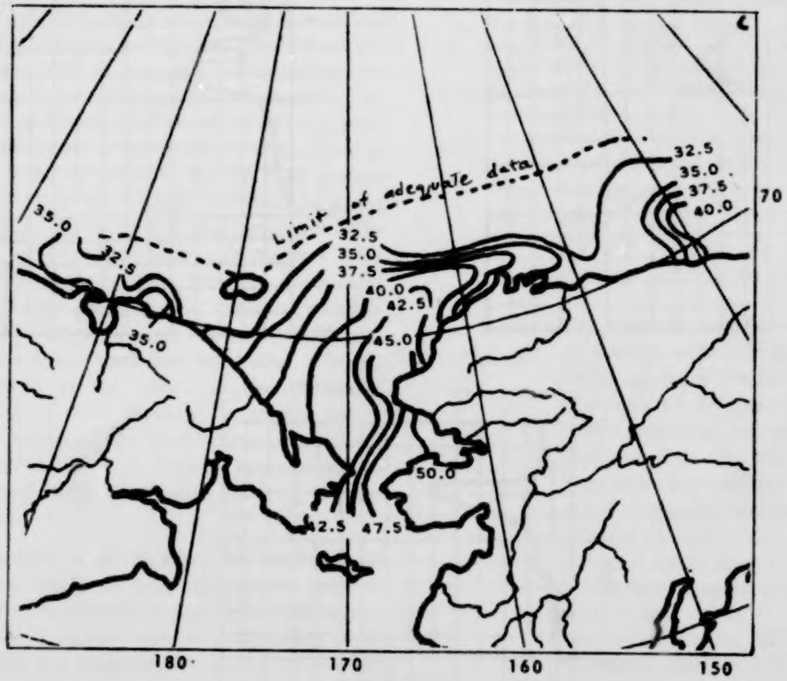

Limit of adequate data
32.5
35.0
37.5
40.0
70
35.0
32.5
35.0
32.5
35.0
37.5
40.0
42.5
45.0
50.0
42.5
47.5
180
170
160
150

Figure 3-XIV. Chukchi Sea — Average Sea Surface Temperature in August (°F)

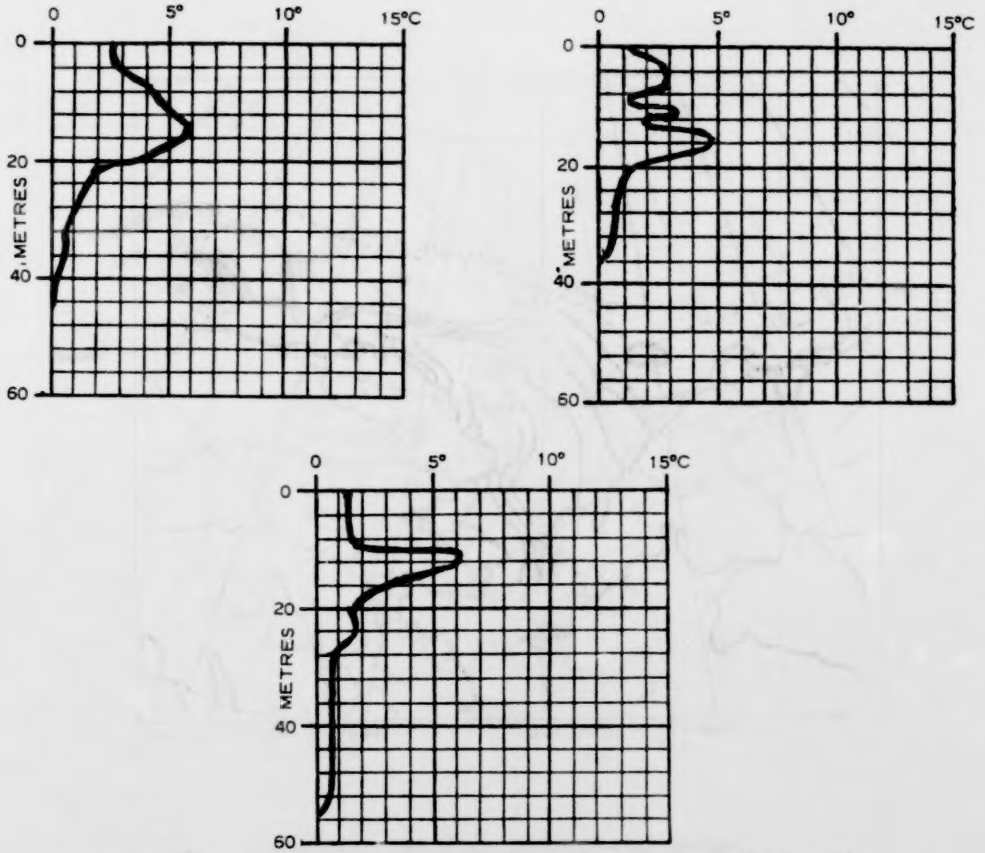


Figure 3-XV. Bathythermograph Samples in the Chukchi Sea — Summer Conditions in the Ice Pack

310. WESTERN NORTH AMERICAN WATERS

a. *Bathymetry.* The continental shelf between Point Barrow and Cape Prince Alfred varies in width from less than 50 miles (80 km.) in the west to nearly 100 miles (160 km.) in the centre and northeast. Off Alaska the cross profile is characteristic of the continental oceanic margin in all parts of the world, consisting of the flat sheif and a steep upper continental slope that decreases as the Canada Basin is reached at about 2000 fathoms (3658 m.). East of the border the slope diverges from the mainland in a swinging arc towards northwestern Banks Island, and the upper slope is gentler in this area than farther west. The continental shelf is crossed by several deep valleys. In the west is the Barrow Sea Valley which originates off Cape Franklin and deepens northeastwards to become 20 miles (35 km.) wide and U-shaped north of Point Barrow. A second valley is 55 miles (90 km.) to the east. Northwest of Mackenzie Bay is the Mackenzie Sea Valley, a broad, flat-bottomed valley leading from the outlet of the Mackenzie River; 140 miles (225 km.) to the northeast a smaller valley has been recognized. The largest of the shelf valleys is a broad, asymmetrical feature, the Amundsen Trough, between Banks Island and the mainland. It has an average width of 24 miles (40 km.) and the floor is at about 240 fathoms (439 m.).

b. *Currents.* Surface currents in the Beaufort Sea are light and probably irregular, depending largely on wind and pressure changes. The clockwise circulation of the Arctic basin sets southwest and west at roughly 2.5 nautical miles/day (5 cm./sec.) over the continental slope, but there is little evidence that it is found inshore. Along the Alaskan coast there is thought to be a reverse (eastwards) current.

311. EASTERN NORTH AMERICAN WATERS (north of a line, Resolution Island – Kap Farvel)

a. *General*

(1) The eastern North American Arctic is centered around the waters of Baffin Bay which is connected to the Arctic Ocean through the channels leading west and north through the Queen Elizabeth Islands and to the Atlantic Ocean through Davis Strait into the Labrador Sea. The body of water separating west Greenland and northeastern Canada forms a 1200 mile long channel (1,900 km.) from the Arctic Ocean to the Labrador Sea. The opposing coasts are remarkably similar and it has been suggested that Baffin Bay resulted from uparching of part of the Greenland-Canadian Shield; subsequently the arch collapsed and was submerged as continental drift occurred between Greenland and Canada.

(2) The waters in eastern North America reflect the meeting of warmer waters from the Atlantic with the frigid waters of the Arctic Ocean and are in a large measure controlled by the bathymetry of the area. Baffin Basin, with a maximum depth of 1100 fathoms (2012 m.) is separated from the Labrador Sea by the Davis Strait ridge which has maximum depths near 400 fathoms (730 m.). The adjacent channels shallow to depths of 80–100 fathoms (146–183 m.) to limit the influence of the Arctic Ocean to those waters found above those depths. Sea surface temperatures reach a maximum in August with a high of 48°F (8.9°C) in the Labrador Sea. Temperatures above 40°F (4.5°C) are found along the Greenland coast to 73° N and in the "North Water" off the entrance to Lancaster Sound. In the channels temperatures are near 32°F (00°C) and warm to 35°F (1.7°C) as the waters approach Baffin Bay. The Arctic influence of the Canadian Current along the east coast of Baffin Island is reflected in the depressed temperatures, 32.5–38°F (0.3 to 3.3°C). Summer salinities are as low as 25 percent in the islands near the ice edge. Along the coasts they are near 30.0 percent in the Labrador Sea.

(3) Tides in the area are of Atlantic origin and course through Davis Strait. Only in the extreme north are Arctic tides in evidence. Time of high waters at the head of the Gulf of Boothia occurs twelve hours after that in the southern limits of the area. Tidal ranges are near 6-10 ft. over most of the region, but go to 12 ft. on the southern side of Davis Strait and are over 40 ft. at the head of Frobisher Bay. Tidal currents are extremely variable throughout the region, being generally light in open waters and as high as 7 kts. in areas of large tidal ranges.

(4) The general surface circulation, like the temperature and salinities, reflect the influences of the Arctic and Atlantic Oceans. The West Greenland Current flows northward from Kap Farvel at speeds of 0.5 kts. in Davis Strait. This current carries around the head of Baffin Bay where it is joined by waters flowing southward through the islands to form the Canadian Current, which flows along the east coast of Baffin Island. After crossing Davis Strait ridge the Canadian Current is joined by the west-flowing branch of the West Greenland Current to form the Labrador Current. In the channels between the islands currents are about 0.5 kts., while the Canadian Current has velocities of about 0.2 kts. In the Gulf of Boothia the waters flow southward and exit through Fury and Hecla Strait into Foxe Basin.

(5) Because eastern Arctic America extends through more than 20° of latitude there are extensive climatic differences. In general, the Canadian portion is colder than the Greenland coast in winter, with many storms in the southern sector. During the summer season there is a greater uniformity of weather over the whole area. The cold sea has a strong influence on coastal weather, creating much fog and cloud and keeping temperatures below 15°C.

b. *Bathymetry*

(1) The bathymetry of the northeast American Arctic basically consists of the shallow areas to the north in which are located the islands of the Canadian Archipelago with relatively deep channels and the deep Baffin Bay basin (1250 fathoms: 2286 m.) which is separated from the Atlantic by Davis Strait Ridge.

(2) At the entrance to the area from the Atlantic the bottom shoals gradually from the depths of the Labrador Basin (2200 fathoms: 4024 m.) to the Davis Strait Ridge where depths are less than 400 fathoms. This ridge separates the Labrador Basin from the Baffin Bay Basin where depths exceed 1000 fathoms (1829 m.) On the Canadian side of the Labrador Sea, the 100 fathoms line is very narrow and is cut by the deep fiords of Frobisher Bay and Cumberland Sound. The Greenland shelf is well defined and narrow near Kap Farvel, broadens northward to form Fylla, Little Hellefiske and Great Hellefiske Banks. North of Disko Island the continental shelf narrows and all but disappears near Cape York. Along the Baffin Island shore the shelf is narrow.

(3) The channels between the Arctic islands are deep where they join the major basins in the area. However, in every case they have shallow ridges which limit the depth and hence types of waters that may be drawn through them.

(4) The narrow channel that separates Canada from northwest Greenland consists of two basins, Hall and Kane, joined by Robeson and Kennedy Channels and Smith

Sound. In the north, at the narrowest part, the two shores are separated by only 12 miles (20 km.) of water. The topography of the sea floor is hummocky. The shallowest part is in the north part of Kane Basin where the sill depth is 50–100 fathoms (91–183 m.). The floor slopes away in both directions to 200–250 fathoms (366–457 m.) in the Lincoln Sea, and to about 350 fathoms (640 m.) at the south end of Smith Sound.

(5) The bathymetry of Jones Sound is not well known. In the central part depths of 400 fathoms (732 m.) have been reported. Lancaster Sound has a wide flat floor that drops eastwards to 450 fathoms (823 m.) where it enters Baffin Bay. As in Jones Sound, submerged valleys enter the main trough from the side fiords and channels. Lancaster Sound reaches a minimum depth of 50 fathoms (90 m.) near Cornwallis Island in Barrow Strait.

(6) Prince Regent Inlet (Gulf of Boothia) and Admiralty Inlet have similar bathymetric features. Both are extremely shallow at the southern end. Depths increase northwards in what are considered submerged glacial throughs, to greater than 450 fathoms (823 m.) in Admiralty Inlet and 260 fathoms (475 m.) in the Gulf of Boothia. Sills with depths of 180 fathoms (329 m.) separate them from Lancaster Sound.

c. *General Circulation*

NOTE: Figure 3-XVI shows a general scheme of the ocean circulation.

(1) At Kap Farvel the waters of the West Greenland Current follow the Greenland coast to the north. Over the continental shelf the waters are colder and fresher than those just beyond the shelf edge. On approaching Davis Strait the warm waters are deflected westwards toward Baffin Island. The cold waters are depleted through mixing in their northward flow so that the extension of the West Greenland Current over the Davis Strait ridge is relatively warm. This warmth is reflected in weather conditions and ice coverage as described in Chapters 2 and 4.

(2) By the time the north-flowing waters have reached the vicinity of Cape York, a large portion of the heat content has been dissipated. However, they are still warmer and more saline than the waters flowing southward from the Arctic Ocean, which are below freezing even in mid-summer.

(3) The joining of the waters of the extension of the West Greenland Current with those flowing through the Arctic islands, forms the Canadian Current which flows southward along the Baffin Island coast. This current is of frigid character, carrying with it sea ice and icebergs. In the area south of Davis Strait it is joined by the warm waters of the West Greenland Current to form the Labrador Current.

(4) The waters in the three sounds bordering the northwest corner of Baffin Bay have a strong set towards the Bay, with their freight of cold low-salinity water. At greater depths there is a draw-in of the warmer high-salinity water from Baffin Bay to replace the water consumed in the mixing process with the waters from the Arctic Ocean. This effect is most noticeable in Lancaster Sound.

(5) In the northern part of Baffin Bay and Smith Sound

there is an area described as "North Water". In this region summer sea surface temperatures have been reported as consistently warmer than in surrounding areas. In winter various sources attribute it to be ice free during all or most of the year. Various reasons for the existence of the "North Water" have been advanced. The most recent one considered is that it is due to the nature of the circulation which keeps it ice-free and hence allows the surface waters to be warmed through insolation.

(6) In central Baffin Bay the waters tend to flow slowly in a large anti-clockwise gyre.

d. *Thermal Structure (Summer)*

(1) Figure 3-XVII shows selected examples of the thermal structure throughout the area for the summer, with their locations shown in Figure 3-XVIII. It is to be noted that in only one instance did temperatures exceed 41°F (5°C), although temperatures as high as 46.5°F (8°C) have been observed at the entrance to Lancaster Sound ("North Water").

(2) In general, below 20 fathoms (36 m.) temperatures are uniformly cold with gradual warming noticeable in the extreme north (15, 16) due to warmer Atlantic waters in the Arctic Ocean entering the deep channel, and in the south (2) due to warmer waters of the adjacent Atlantic. In winter, temperatures are near 29°F (−1.5°C) throughout the area north of Davis Strait, and between 35°–39°F (2–4°C) at the southern boundary, except near the coast where temperatures are below 32.0°F (0.0°C). The influence of the East Greenland Current as it rounds Kap Farvel (1) is shown by the cooler waters in the upper 28 fathoms (50 m.).

(3) Above 20 fathoms (36 m.) strong negative gradients occur, and these are coupled with strong salinity gradients. In one instance (12) a strong positive gradient at the surface suggests cooling due to ice movement.

(4) Depressed sound channels are present throughout the summer, but are relatively weak due to the small contrast in temperatures in the water column.

312. HUDSON BAY–FOXE BASIN–LABRADOR SEA

a. *Bathymetry*

(1) *Foxe Basin.* Foxe Basin is exceptionally shallow. A large part of the southeast and northwest sectors are less than 20 fathoms (36 m.) deep, with tidal flats that are 10-15 miles (18-28 km.) wide near Bowman Bay. Contrasting strongly with these conditions, depths of 100-250 fathoms (183-457 m.) occur in Foxe Channel where there is a broad submarine trough adjacent to Southampton Island.

(2) *Hudson Bay.* Hudson Bay is an inland sea 200,000 square miles (518,000 sq. km.) in area; the average depth is about 50 fathoms (91 m.) and the maximum depth is 150 fathoms (274 m.). Several of the main river valleys entering Hudson Bay can be traced on the sea bed for considerable distances and are part of an original drainage system that flowed northeast into Hudson Strait. James Bay, with an area of 20,000 square miles (52,000 sq. km.) is even shallower than Hudson Bay. The deepest part is a little more than 25 fathoms (46 m.) and occurs in an elongated sea floor depression that bends north-south just east of the centre of the bay.

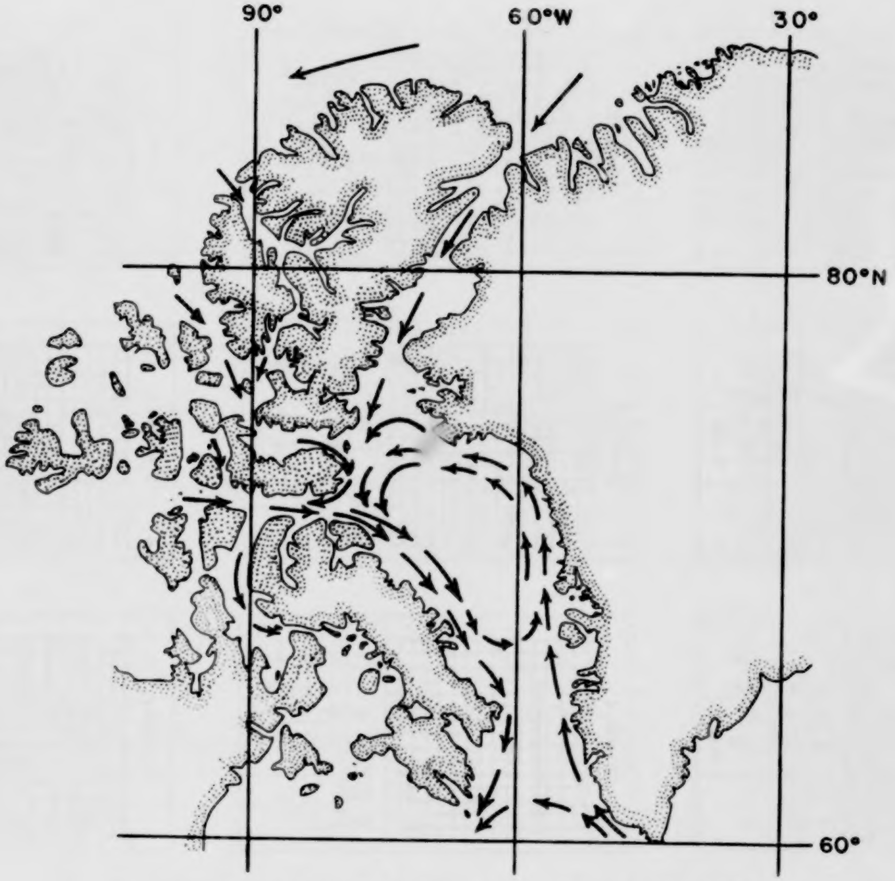
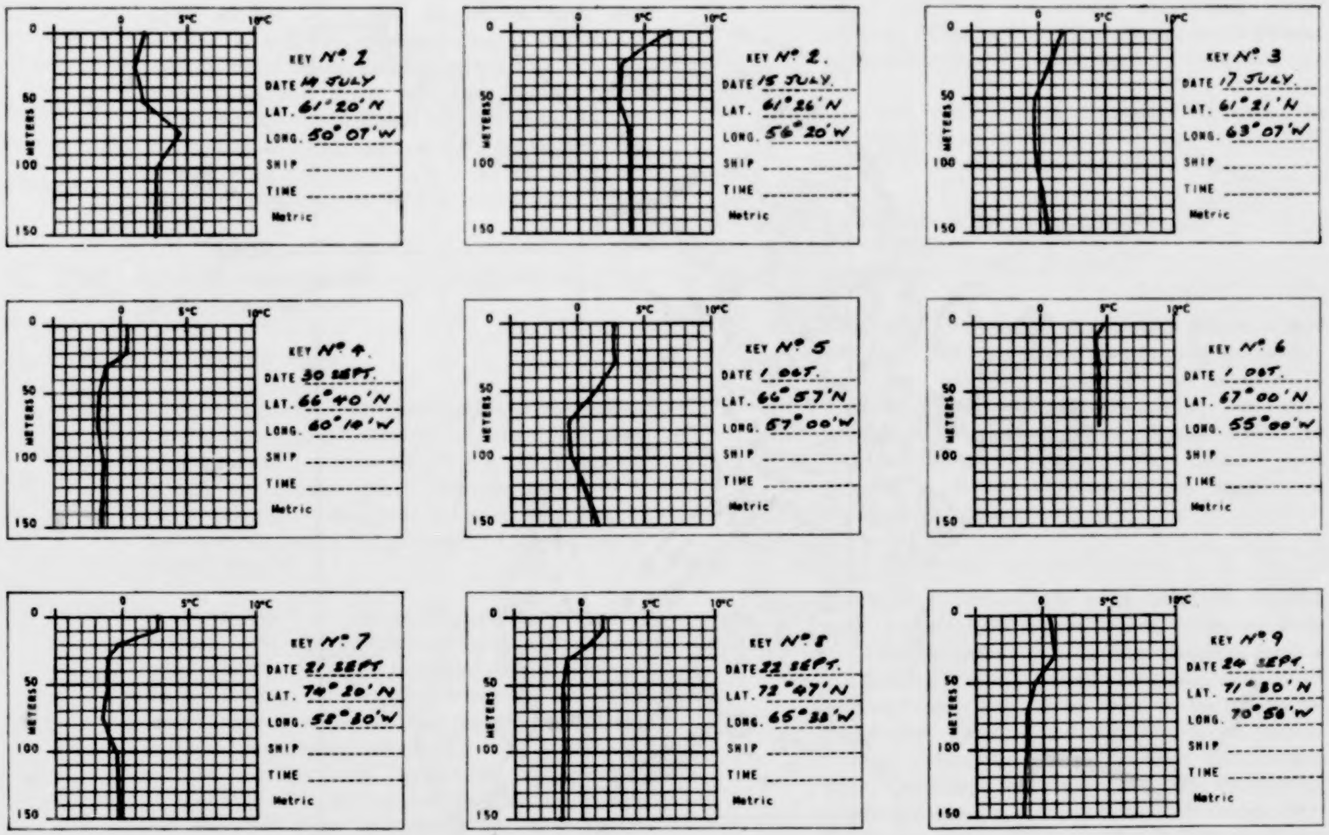

90°
60°W
30°
80°N
60°

Figure 3-XVI. General Circulation – Eastern North American Waters



KEY Nº 1
DATE 14 JULY
LAT. 61°20'N
LONG. 50°07'W
SHIP
TIME

KEY Nº 2.
DATE 15 JULY.
LAT. 61°26'N
LONG. 56°20'W
SHIP
TIME

KEY Nº 3
DATE 17 JULY.
LAT. 61°21'N
LONG. 63°07'W
SHIP
TIME

KEY Nº 4.
DATE 30 SEPT.
LAT. 66°40'N
LONG. 60°14'W
SHIP
TIME

KEY Nº 5
DATE 1 OCT.
LAT. 66°57'N
LONG. 57°00'W
SHIP
TIME

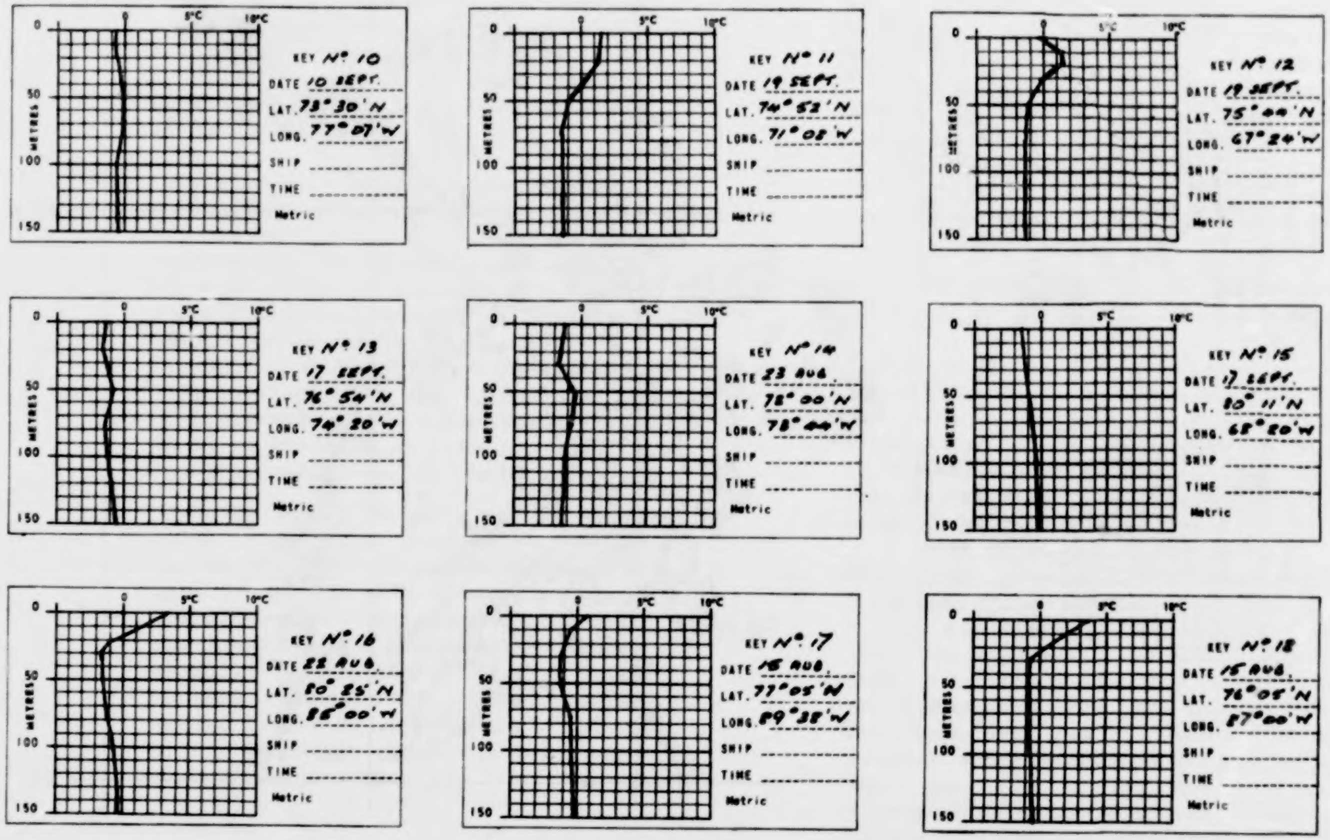
KEY Nº 6
DATE 1 OCT.
LAT. 67°00'N
LONG. 55°00'W
SHIP
TIME

KEY Nº 7
DATE 21 SEPT
LAT. 74°20'N
LONG. 58°30'W
SHIP
TIME

KEY Nº 8
DATE 22 SEPT.
LAT. 73°47'N
LONG. 65°38'W
SHIP
TIME

KEY Nº 9
DATE 24 SEPT.
LAT. 71°30'N
LONG. 70°56'W
SHIP
TIME

Figure 3-XVII. Bathythermograph Samples – Eastern North American Waters
(see Figure 3-XVIII)



KEY N° 10
DATE 10 SEPT.
LAT. 73° 30' N
LONG. 77° 07' W

KEY N° 11
DATE 19 SEPT.
LAT. 74° 52' N
LONG. 71° 08' W

KEY N° 12
DATE 19 SEPT.
LAT. 75° 44' N
LONG. 67° 24' W

KEY N° 13
DATE 17 SEPT.
LAT. 76° 54' N
LONG. 74° 20' W

KEY N° 14
DATE 23 AUG.
LAT. 78° 00' N
LONG. 78° 44' W

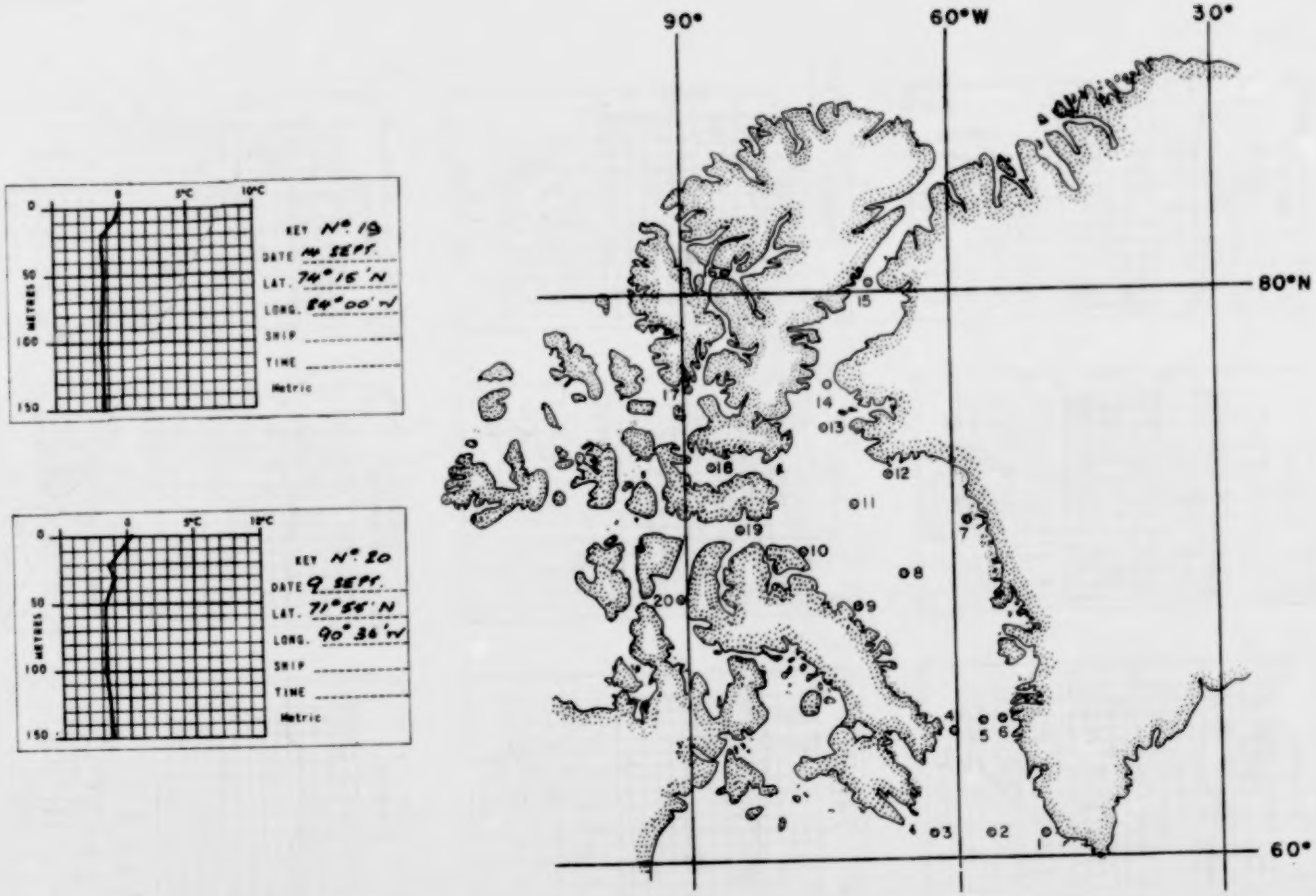
KEY N° 15
DATE 17 SEPT.
LAT. 80° 11' N
LONG. 68° 20' W

KEY N° 16
DATE 22 AUG.
LAT. 80° 25' N
LONG. 85° 00' W

KEY N° 17
DATE 15 AUG.
LAT. 77° 05' N
LONG. 89° 38' W

KEY N° 18
DATE 15 AUG.
LAT. 76° 05' N
LONG. 87° 00' W

Figure 3-XVII (Cont'd). Bathythermograph Samples – Eastern and North American Waters
(see Figure 3-XVIII)


0
5°C
10°C
0
50
100
150
METRES
Metric
0
5°C
10°C
0
50
100
150
METRES
Metric
90°
60°W
30°
80°N
60°
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

KEY N° 19
DATE 14 SEPT.
LAT. 74° 15' N
LONG. 84° 00' W
SHIP
TIME

KEY N° 20
DATE 9 SEPT.
LAT. 71° 55' N
LONG. 90° 36' W
SHIP
TIME

Figure 3-XVIII. Location of Bathythermograms – Eastern North American Waters (see Figure 3-XVII)

(3) *Hudson Strait.* Hudson Strait is a deep trough joining Hudson Bay and Foxe Basin to the Labrador Sea. Mid-channel depths in Hudson Strait range from 300 fathoms (549 m.) at the eastern entrance to 190 fathoms (347 m.) in the western extremes. Ungava Bay near the eastern end of the strait has central depths in excess of 184 fathoms (336 m.).

(4) *Labrador Sea and Newfoundland Waters.* Figure 3-XIX shows the bottom configuration to 1,000 fathoms (1829 m.). Noteworthy features are the broad and deeper continental shelf (200 fathoms: 366 m.) that generally follows the coastline and expands into the wide and shallow Grand Banks. In some areas near Newfoundland depths of 100 fathoms (183 m.) are found very close to the coast in fiords. Beyond the 200 fathoms (366 m.) contour, depths increase rapidly to 1,000 fathoms (1829 m.). In contrast to this, depths of less than 30 fathoms (88 m.) are found along the southeastern face of the Grand Banks over 250 miles from land.

(5) *Gulf of St. Lawrence.* The gulf of St. Lawrence is a shallow continental sea penetrated by two deep channels. The larger channel extends from the continental shelf south of Newfoundland almost to the Saguenay River. For much of its distance it is about 235 fathoms (430 m.) deep. A shorter and shallower channel separates from the main trough and then divides again to pass north of Anticosti Island and into the northeast corner of the Gulf. Its average depth is 140 fathoms (256 m.). The southwest portion of the Gulf is shallow and for the most part sandy.

b. *General Circulation*

(1) *Foxe Basin.* The circulation of Foxe Basin is dominated by a southerly flow along the western side of the Basin and a counter-clockwise gyre in the central area south of Prince Charles Island. The southern flow along the western side of Foxe Basin and Foxe Channel transports water and ice into Hudson Bay and Strait. Current speeds in many parts of Foxe Basin are extreme. Currents as high as 6 kts. (309 cm/s) have been reported off Cape Dorchester, and elsewhere speeds of 2-4 kts. (103-206 cm/s) are common. These speeds are tidal in nature, the steady circulatory movements being less than 0.5 kts. (26 cm/s).

(2) *Hudson Bay.* In general, the circulation is anti-clockwise, with a southward flow on the west side and northward flow on the east side of the Bay. The predominant movement of the surface waters is from James Bay northward along the eastern shore, holding close to the coast. A contribution of water from Foxe Basin is made through Roe's Welcome Sound and around the eastern tip of Southampton Island. The main outflow of surface water into Hudson Strait is near Mansell Island and particularly near the Quebec Coast.

(3) *Hudson Strait.* The waters flowing eastward through Hudson Strait originate in Hudson Bay and Foxe Basin. As these waters proceed toward the east they tend to be confined to progressively thinner surface water and finally lose their identity as they reach the waters of the open ocean. A strong segment of the Labrador Current enters Hudson Strait along the Baffin Island coast by rounding Resolution Island and also by passing through Gabriel Strait. Near Big Island there is a major recurvature of these waters to the south side and they flow out of the Strait. The inshore waters continue to flow westward to enter Foxe Basin and also to join the outflowing waters near Salisbury Island.

(4) *Labrador Sea and Newfoundland Waters.* The dominant feature of this region is the Labrador Current. It has been described as a cold water stream which flows southward over the continental shelf inside the comparatively motionless mass of the Labrador Sea. The Labrador Current may be divided into two streams, inshore and offshore. The inshore stream contains the greater volume of cold water and is confined to the continental shelf. This is the portion that enters Hudson Strait and is reinforced by that stream flowing out past Cape Chidley. The offshore stream which contains waters that are characteristic of the warmer West Greenland Current, tends shoreward near Hudson Strait, but does not enter, and continues to flow southward over the continental slope. The characteristic low temperature of the Labrador Current persists as the waters flow southward, the great stability preventing the penetration of solar heat by convection. On reaching the vicinity of Belle Isle Strait, water from the inshore stream is carried at times through the Strait into the Gulf of St. Lawrence. Water moving outward along the southern side of Belle Isle Strait enters into the southward flow of the Labrador Current. Continuing southward of Belle Isle Strait, the Labrador Current meets the northern face of the Grand Banks in the latitude of St. John's and is split, the slope branch continuing down the edge of the Grand Banks while an inshore branch follows the Avalon Channel past Cape Race.

In the Labrador Sea the outermost portion of the slope current curves eastward to join a tongue of warm Atlantic water which extends into the Labrador Sea northeast of the Grand Banks. On the northeast face the cold water keeps to the edge of the Bank while the warmer waters pass out into the Labrador Sea. In the area between the Flemish Cap and the Tail of the Grand Banks, waters from the west meet the Labrador Current with the result that movements are extremely variable both in motion and in water characteristics. It is in this area that the North Atlantic Drift is born. On the shallow Grand Banks the circulation is counterclockwise inside these cold currents. Along the south coast of Newfoundland there is a weak westerly movement that enters the Gulf of St. Lawrence at Cape Ray.

(5) *Gulf of St. Lawrence.* The circulation of the waters, in the upper layers, in the Gulf of St. Lawrence are in general counter-clockwise. Waters that enter the Gulf past Cape Ray are deflected to the right to flow northeastward along the west coast of Newfoundland. Along the north shore of the Gulf the waters drift westward. These waters appear to have originated along the Labrador Coast. The Strait of Belle Isle requires special note because in addition to the regular ebb and flood of the tides other conditions have been observed. The waters may move as a body in one direction or the other so that tidal effects fail to reverse the direction of flow. This phenomenon of "dominant flow" is believed to be caused by meteorological conditions. At other times a progressive movement of Labrador waters to the west along the north side of the Strait and a similar movement of Gulf water eastward along the south side has been observed. In summer, the waters originating in the Gulf of St. Lawrence are warmer than those of Labrador coast origin. The westward flow through the Strait of Belle Isle rounds Cape Whittle to enter Jacques Cartier Passage. Part of the movement in this passage appears to be closely allied to tidal movements, so that there is a net westward movement of water past the

western end of Anticosti Island while at the eastern end there is an eastward movement possibly caused by the shallowing waters in the passage. This current recurves and flows west along the south coast of Anticosti Island where it enters the general circulation of the estuary of the St. Lawrence River.In the Gaspe Passage, between Anticosti Island and the Gaspe Peninsula, there is a predominance of movement to the east which is known as the Gaspe Current. This current is very strong and its effects can be seen and felt for many miles from the coast. It keeps well to the Gaspe Peninsula but loses a considerable amount of its velocity on passing into the shallows of the southern portion of the Gulf. The waters in this southern St. Lawrence Gulf area form a general eastward flow which works toward Cabot Strait, where the main efflux of the Gulf of St. Lawrence takes place. This current in Cabot Strait is known as the Cape Breton Current.

(6) Figures 3-XX and 3-XXI indicate the general circulation of these areas.

c. *Thermal Structure and Water Conditions*

(1) In Foxe Basin, sea surface temperatures because of the small range and ice cover do not exhibit any appreciable geographic variations. The most complete survey was carried out in October, at which time surface temperatures varied between 30° and 32°F (−1.1° and 0.0°C).

(2) Hudson Bay has a summer temperature range of over 14.4°F (8°C) with the warmest part being in the centre of the Bay and the coldest near the shore. The warmed thin surface layer appears to be strongly affected by winds, with the result that warm waters near a windward coast may be blown off and replaced by cold sub-surface waters, while a lee shore may have an abundance of warm water.

(3) Hudson Strait has strong tidal currents which tend to keep the waters well mixed and thus preventing the development of a warmed surface layer. At the western end of the Strait where the outflow of waters from Hudson Bay takes place, the waters from the Bay override those from the Strait, which gives the same effect as a warmed surface layer. This effect is confined to the south side of the Strait.

(4) Figure 3-XXII shows the distribution of surface temperatures in August for the Labrador Sea and Newfoundland waters, and Figure 3-XXIII shows the distribution for March in which extreme winter conditions are prevalent. These charts combined with Figure 3-XXIV show the influence of the currents in the area and their freights of warm and cold waters during the two opposite seasons of the year.

(5) The locations of the temperature traces depicted in Figure 3-XXIV are shown in Figure 3-XXV. Of special interest, aside from the geographical variations, is the comparison between summer and winter conditions. In the Gulf of St. Lawrence and elsewhere in the coastal waters, the low salinity permits the development of strong positive gradients in the winter and large sound channels in the summer. On the Grand Banks a special case exists because of the depth restrictions. The warm oceanic waters do not reach onto the Banks so that in the winter the waters are cooled and mixed to the bottom. In summer the warming is restricted to the thin surface and to slightly warmer waters of the Labrador

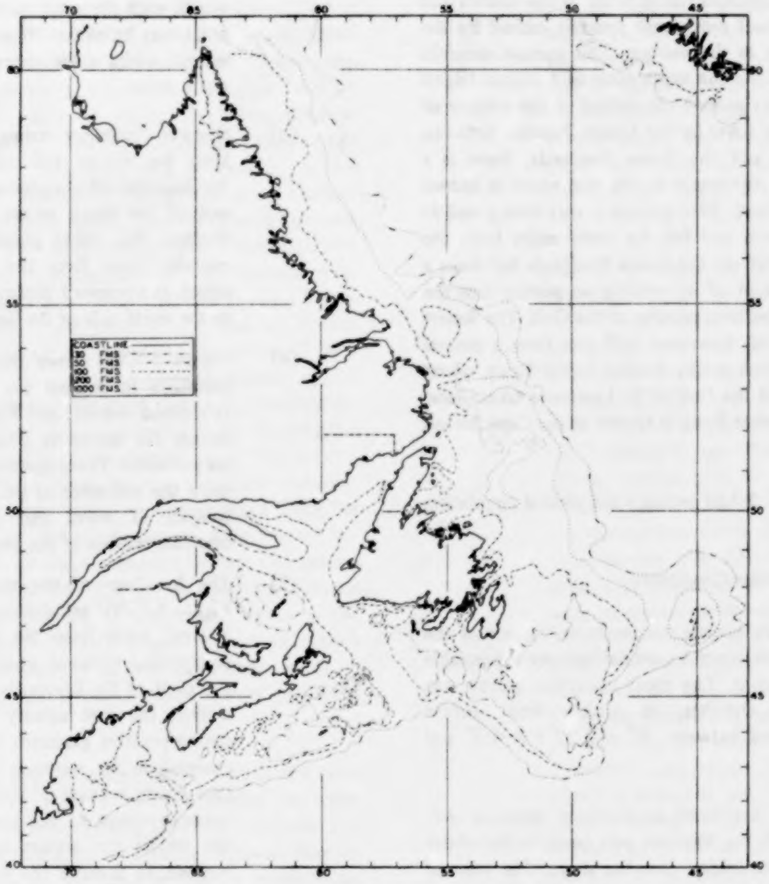

70
65
60
55
50
45
60
55
50
45
40
COASTLINE
30 FMS
50 FMS
100 FMS
200 FMS
1000 FMS

Figure 3-XIX. Bathymetry – Labrador Sea and Newfoundland Waters.

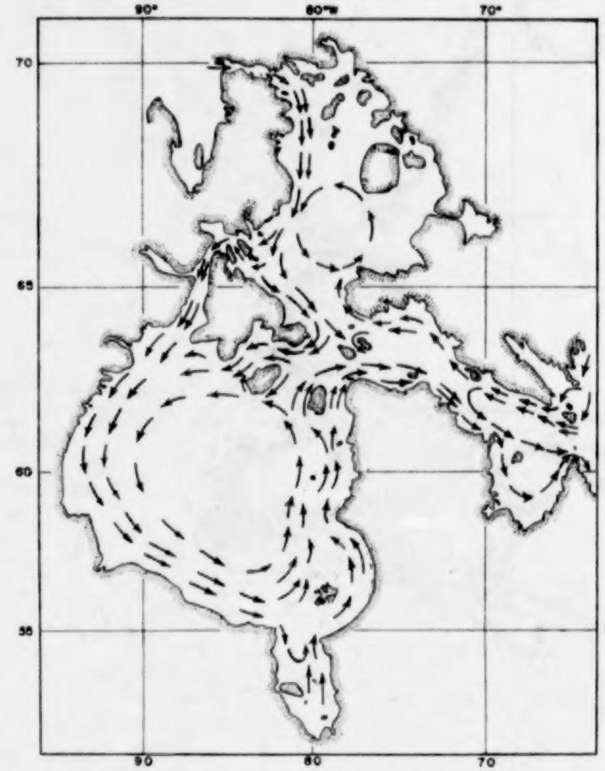

90°
80°W
70°
70
65
60
55
70
65
60
55
90
80
70

Figure 3-XX. General Circulation – Hudson Strait, Hudson Bay and Foxe Basin

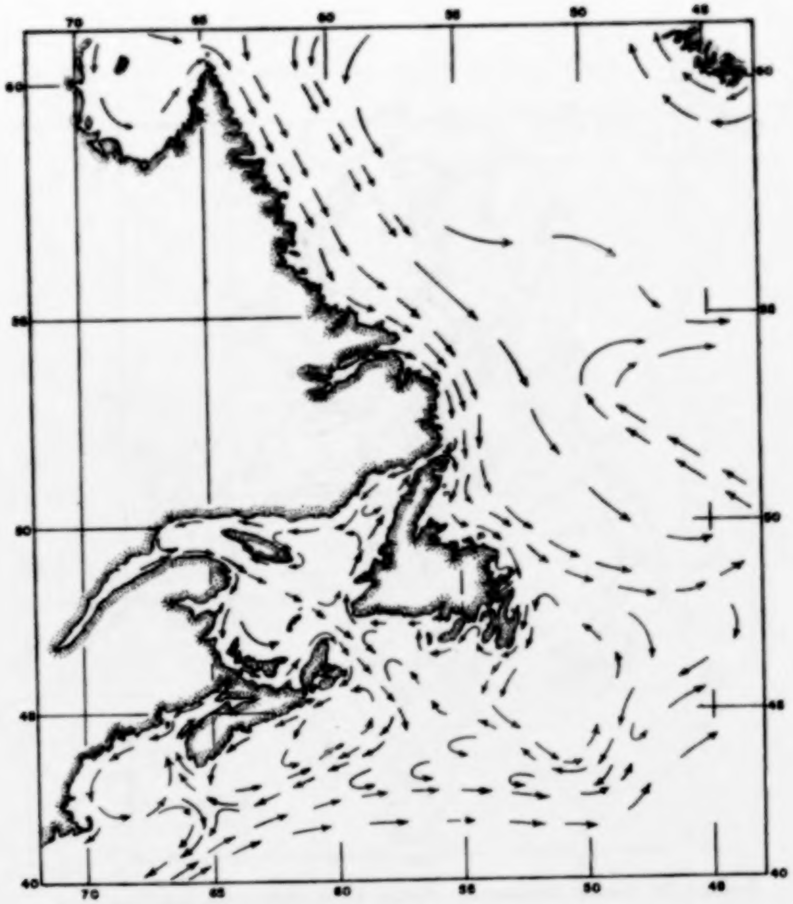
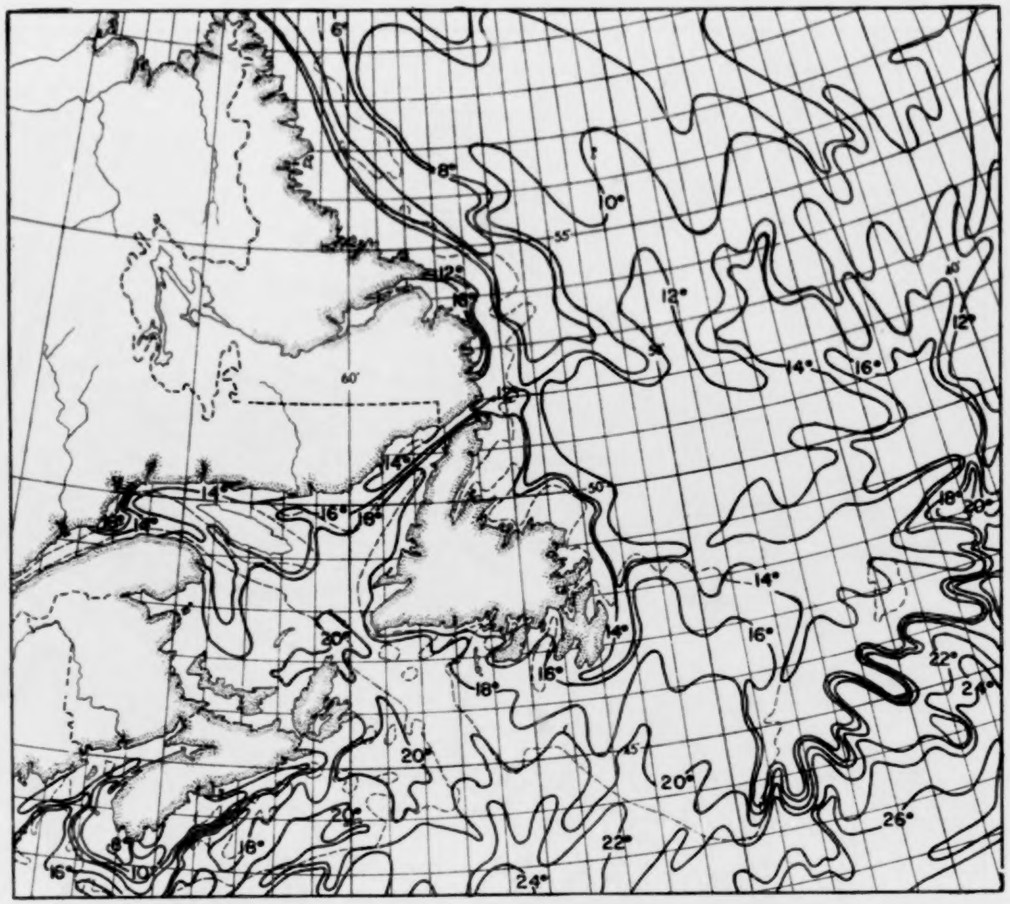

70
65
60
55
50
45
60
55
50
45
40
70
65
60
55
50
45
60
55
50
45
40

Figure 3-XXI. General Circulation – Labrador Sea, Newfoundland Waters and the Gulf of St. Lawrence


6°
8°
10°
55°
12°
16°
12°
12°
14°
16°
12°
60°
14°
14°
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18°
50°
18°
20°
14°
14°
16°
20°
22°
24°
18°
16°
20°
45°
20°
26°
20°
18°
22°
8°
10°
16°
24°

Figure 3-XXII. Distribution of Surface Temperatures in August (°C) in the Labrador Sea, Newfoundland Waters and the Gulf of St. Lawrence

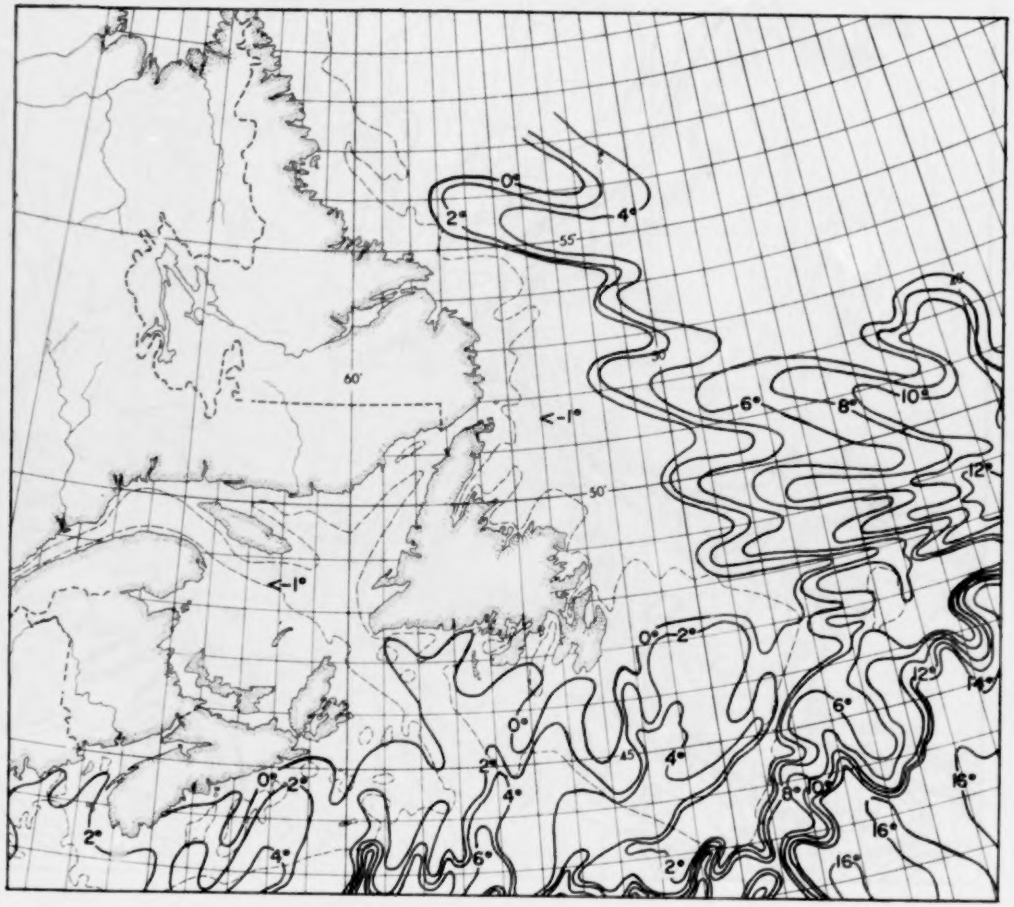
0°
2°
4°
55°
60°
<-1°
50°
6°
8°
10°
12°
<-1°
0°
2°
0°
4°
45
12°
14°
6°
0°
2°
2°
4°
8°
10°
16°
16°
4°
6°
2°
16°

Figure 3-XXIII. Distribution of Surface Temperatures in March (°C) in the Labrador Sea, Newfoundland Waters and the Gulf of St. Lawrence

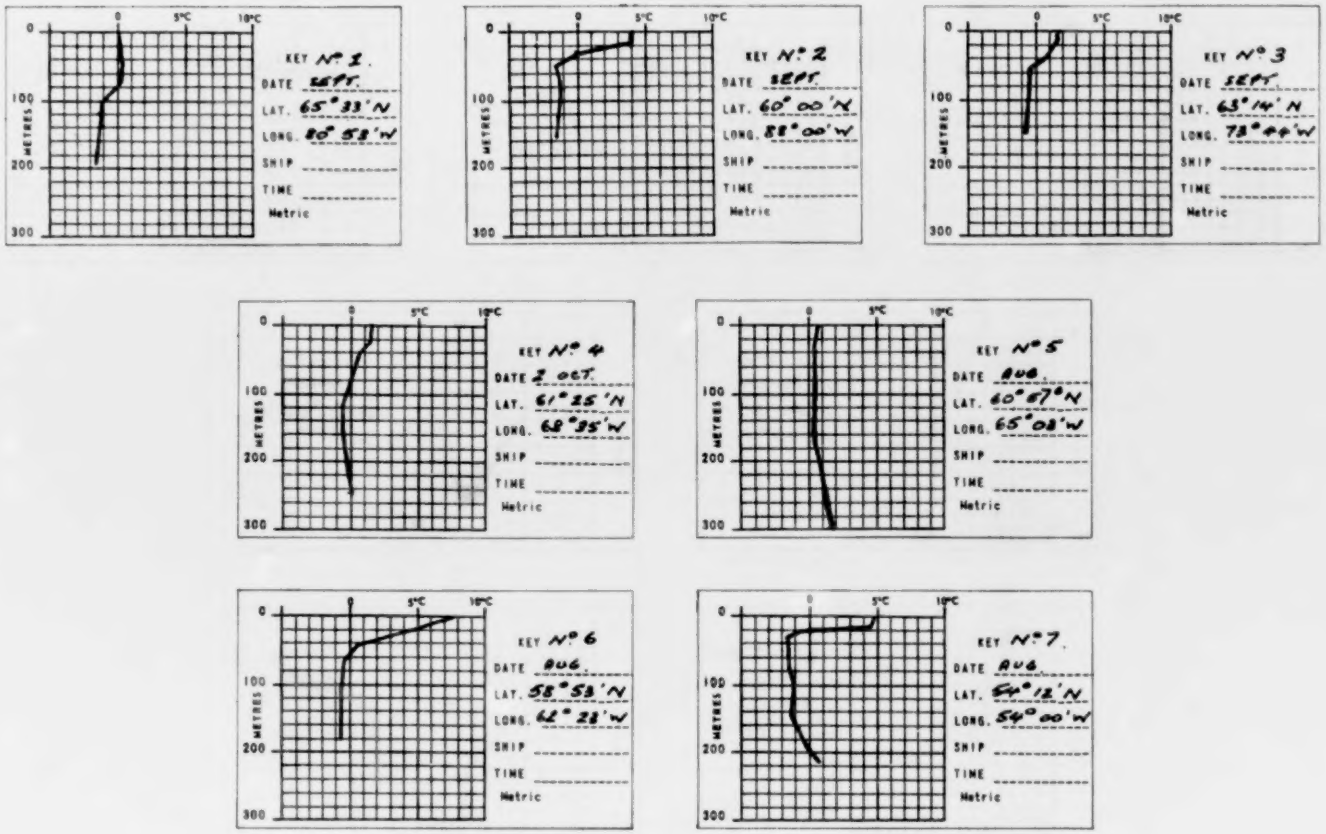

Figure 3-XXIV. Examples of Winter and Summer Bathythermograms — Hudson Bay, Foxe Basin and the Labrador Sea

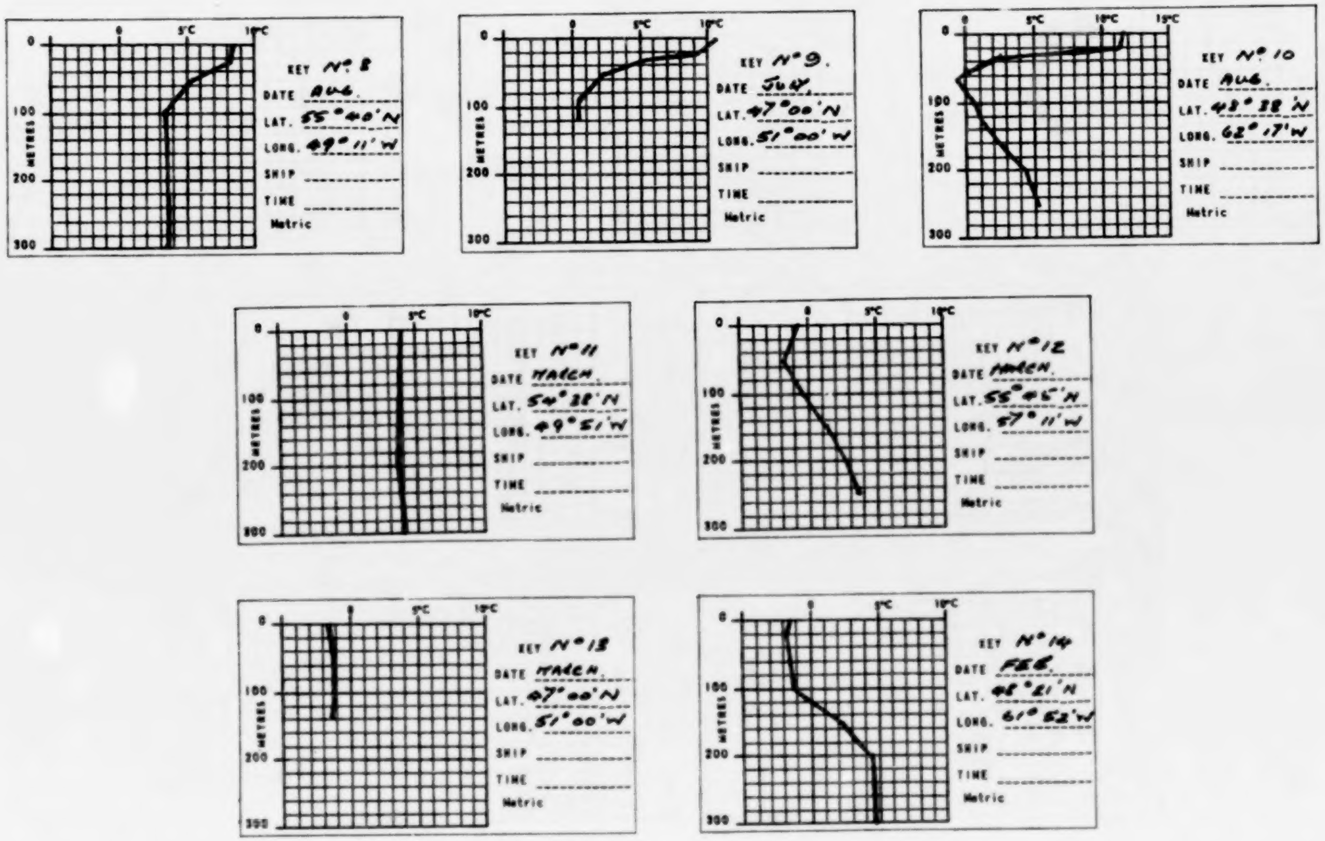

Figure 3-XXIV (Cont'd). Examples of Winter and Summer Bathythermograms – Hudson Bay, Foxe Basin and the Labrador Sea

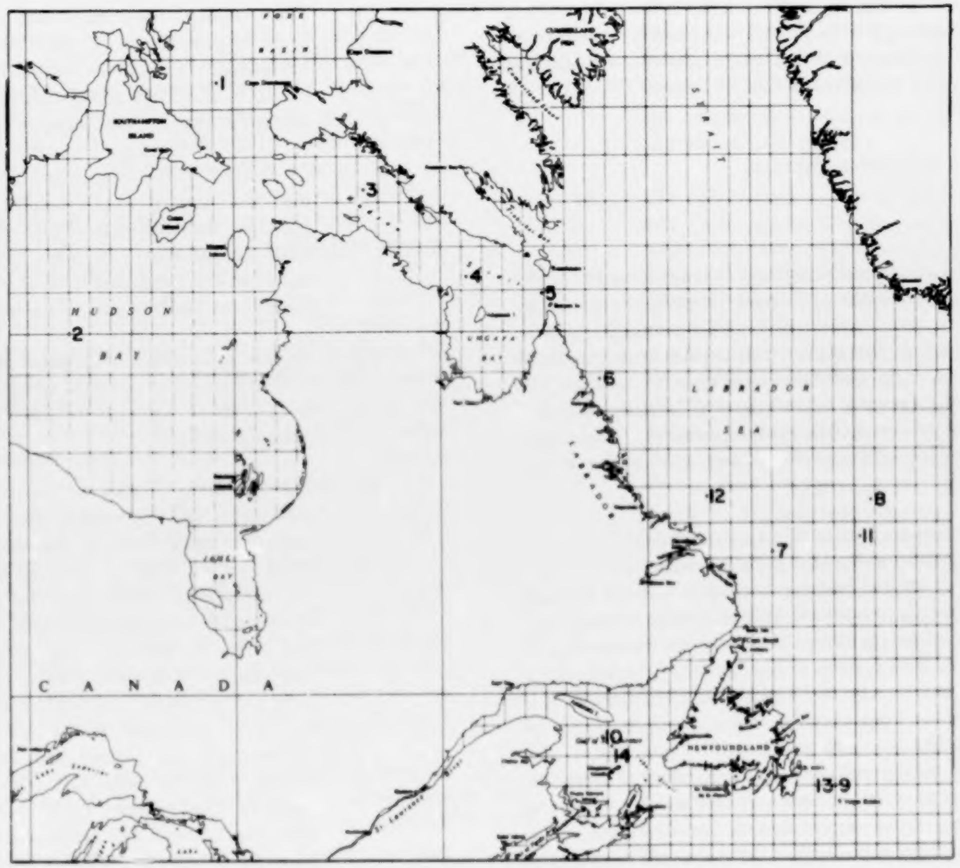
FOXE BASIN
SOUTHAMPTON ISLAND
1
2
3
4
5
6
7
8
9
10
11
12
13
14
HUDSON BAY
UNGAVA BAY
JAMES BAY
STRAIT
LABRADOR SEA
LABRADOR
CANADA
NEWFOUNDLAND

Figure 3-XXV. Locations of Bathythermograms – Hudson Bay, Foxe Basin and the Labrador Sea (refer to Figure 3-XXIV)

Current flooding the banks near the bottom. In contrast, the waters in the Labrador Sea are nearly homogeneous as to temperature in the winter, but show a warming development that reaches to 50 fathoms (91 m.) in the summer.

313. NORTHEAST ATLANTIC WATERS

a. *Bathymetry*

(1) The Norwegian and Greenland Seas are bounded on the west by the Greenland continental shelf and on the east by the Norwegian, Barents and Svalbard continental shelves. The depth of the edges of the shelves varies greatly. A large area of the shelves is deeper than 100 fathoms (183 m.) and frequently extends to 220 fathoms (402 m.). Seaward of the shelves are the continental slopes, with gradients of 1:15 to 1:40, leading down to the abyssal plains.

(2) The Norwegian shelf is 50-140 miles (90-260 km.) wide in its southern and central parts, but narrows to 10 miles (19 km.) off the Lofoten Islands. It is more irregular than normal continental shelves and is crossed by a number of trough-like gullies; these are associated with the major fiord systems of Norway. The Svalbard shelf is narrow and is only 10-40 miles (20-75 km.) wide. It is traversed by deep canyons originating in the fiords of Vest Spitsbergen such as Kongsfjord and Isfjord. The Svalbard shelf stretches to the banks south of Bjornöya, and from there to the banks off northern Norway is the shelf area of the western Barents Sea. This shelf area is deeper and less irregular than the shelves off Norway and Svalbard.

(3) The Greenland continental shelf north of the Denmark Strait is generally broad (60-170 miles: 110-315 km.) but narrows to about 15 miles (28 km.) in the extreme north. It is widest at the Belgica Bank. Typically the bottom is irregular and rough, but local smooth areas are common and there are a number of shoal areas less than 55 fathoms (101 m.) in depth. Troughs are present in the shelf and are both parallel and normal to the shoreline. South from the Denmark Strait the Greenland Shelf narrows from 170 miles (315 km.) in width to 25 miles (45 km.) at Kap Farvel. It is crossed by prolongations of the fiords of east Greenland.

(4) Around Iceland the continental shelf is up to 80 miles (150 km.) wide in the west and north and 50 miles (90 km.) in the east, but off the south coast it narrows to 10 miles (20 km.).

(5) The dominant feature of the central parts of the Norwegian and Greenland Seas is the mid-oceanic mountain range forming the Iceland-Jan Mayen and Mohn Ridges. This is the continuation of the Mid-Atlantic Ridge, which runs the entire length of the North and South Atlantic Oceans, and which rises above sea level in Iceland. The Mid-Atlantic Ridge is characterized in its most elevated region by a central rift zone and by the fact that earthquake epicentres tend to lie on or very near to its axis. These features are continued in the Iceland and Jan Mayen Ridges. A narrow, deep rift valley, 2-3 miles (4-5 km.) wide at a depth of 1800 fathoms (3292 m.) extends along their axial lines and has well developed structural benches on its walls. It ends at 78°30′ N where it meets the Vest Spitsbergen block. The width of the rift mountains and

flanks on each side of this rift is about 35 miles (65 km.) and the crests lie at depths less than 1200 fathoms (2195 m.) but the mountains to the east of the rift are not easily discernible in the Greenland Sea and may have been buried. On both flanks of the ridges are many seamounts. The mountains of the ridge systems rise above the sea as the island of Jan Mayen. A massive, almost unbroken ridge (the South Jan Mayen Ridge) runs south from the island with least depths between 440 – 600 fathoms (805 – 1097 m.).

(6) The Greenland Sea Basin was formerly considered to be separated from the North Polar Basin by the Nansen Sill, but recent Soviet expeditions have shown that a continuous sill does not exist and that it is cut through the middle at about 1°E longitude by the deep Lena Trough, the minimum depth of which is 1700 – 1900 fathoms (3109 – 3475 m.). The mid-oceanic ridge turns in a northwesterly direction from a region to the west of Prins Karls Forland (Vest Spitsbergen) and runs in what is known as the Spitsbergen Fracture Zone to the northeastern tip of Greenland. This results in a bottom topography with a complicated ridge and trench structure. To the east of this zone is the gently undulating Yermak Plateau, which extends for 130 miles (240 km.) from the northwestern corner of Vest Spitsbergen with its crest at depths shallower than 500 fathoms (914 m.).

(7) The basin of the Norwegian Sea is separated from the abyssal plains of the northernmost Atlantic, with depths down to 1600 fathoms (2926 m.), by the Scotland-Greenland Ridge. The eastern part, between Scotland and the Faroes, is mainly less than 330 fathoms (604 m.) in depth, but between Faroe Bank and the Faroe Islands is a narrow channel through the ridge with a sill depth of about 450 fathoms (823 m.) and a least width of about 13 miles (24 km.). The Faroes-Iceland Ridge lies mainly at a depth of 220 – 280 fathoms (402 – 512 m.) with the central part shallower than 220 fathoms (402 m.) and having several peaks.

(8) The deeper parts of the Norwegian Sea can be divided into three regions. The Iceland basin lies between the Iceland-Jan Mayen and South Jan Mayen Ridges and has depths of 1100 – 1400 fathoms (2012 – 2560 m.) in its deepest part. The Norwegian Abyssal Plain, to the east of the South Jan Mayen Ridge, is the most extensive of the three regions and has a considerable area deeper than 1900 fathoms (3475 m.). To the east it is bounded by the Norwegian Plateau, a flat-topped feature generally shallower than 1100 fathoms (2012 m.) An extension of this plateau to the northwest separates the Norwegian Abyssal Plain from the Lofoten Abyssal Plain. This third region is relatively extensive and it has a large area greater than 1800 fathoms (3292 m.) in depth. It is bounded on the north by the Mohn Ridge. Beyond the Mohn Ridge is the basin of the Greenland Sea. It consists in the south of the Greenland Abyssal Plain at a depth of 2000 fathoms (3658 m.). (Figure 3-XXVI.)

b. *Water Masses and Currents*

(1) The water masses of the area together with their temperature and salinity characteristics are listed in Table 3-II, whilst the distribution of these water masses, as far as the upper layers of the ocean are concerned, is shown in Fig. 3-XXVII. The temperature distribution at 110 fathoms (201 m.) depth, and the sea surface temperature isotherms at 5°C intervals for one of the coldest months (February) and one of the warmest

Table 3-II. Temperature and Salinity Characteristics of the Water Masses of the European and American Arctic and Sub-Arctic Seas

Northeast Atlantic Water	9.5°C; 35.35°/oo
Irminger Atlantic Water	4.6°C; 34.95-35.10°/oo
Arctic Water	< 0°C; < 34.0°/oo
Labrador Sea Water	3.4°C potential temperature; 34.89°/oo
Northeast Atlantic Deep Water	3.0°C potential temperature; 34.95°/oo
Northeast Atlantic Bottom Water	0.8° - 1.5°C; 34.91°/oo
Norwegian Sea Deep Water	< 0°C; 34.92°/oo
Arctic Intermediate Water	0°-2°C; 34.8-35.0°/oo
North Icelandic Winter Water	2°-3°C; 34.85-34.9°/oo
Skagerrak Water	3°-16°C (according to season); < 34°/oo

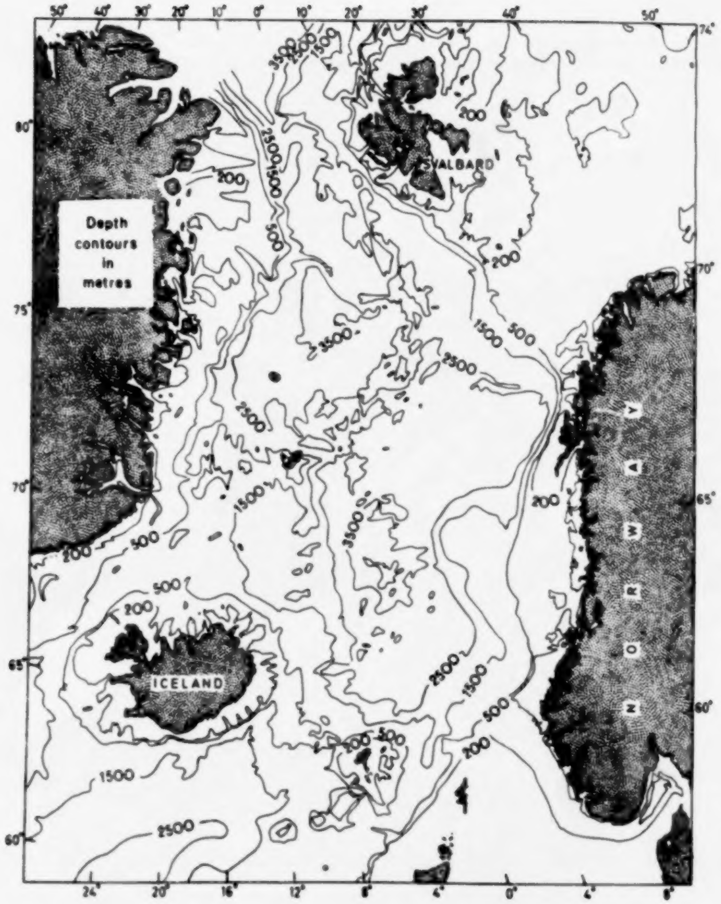
Depth contours in metres
SVALBARD
ICELAND
NORWAY
200
500
1500
2500
3500
50°
40°
30°
20°
10°
0°
10°
20°
30°
40°
50°
74°
80°
75°
70°
65°
60°
70°
65°
60°
24°
20°
16°
12°
8°
4°
0°
4°
8°

Figure 3-XXVI. Depth Contours in Metres – Norwegian and Adjacent Seas

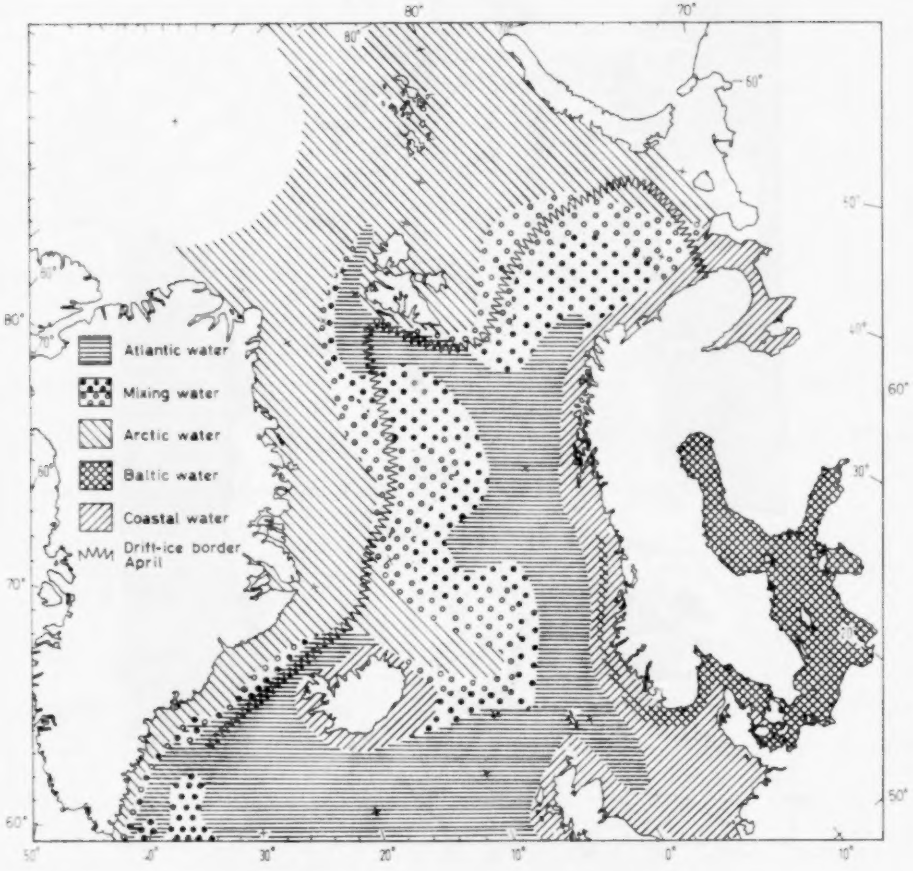
Atlantic water
Mixing water
Arctic water
Baltic water
Coastal water
Drift-ice border April
80°
70°
60°
50°
40°
30°
20°
10°
0°

Figure 3-XXVII. Water Masses — Norwegian and Adjacent Seas

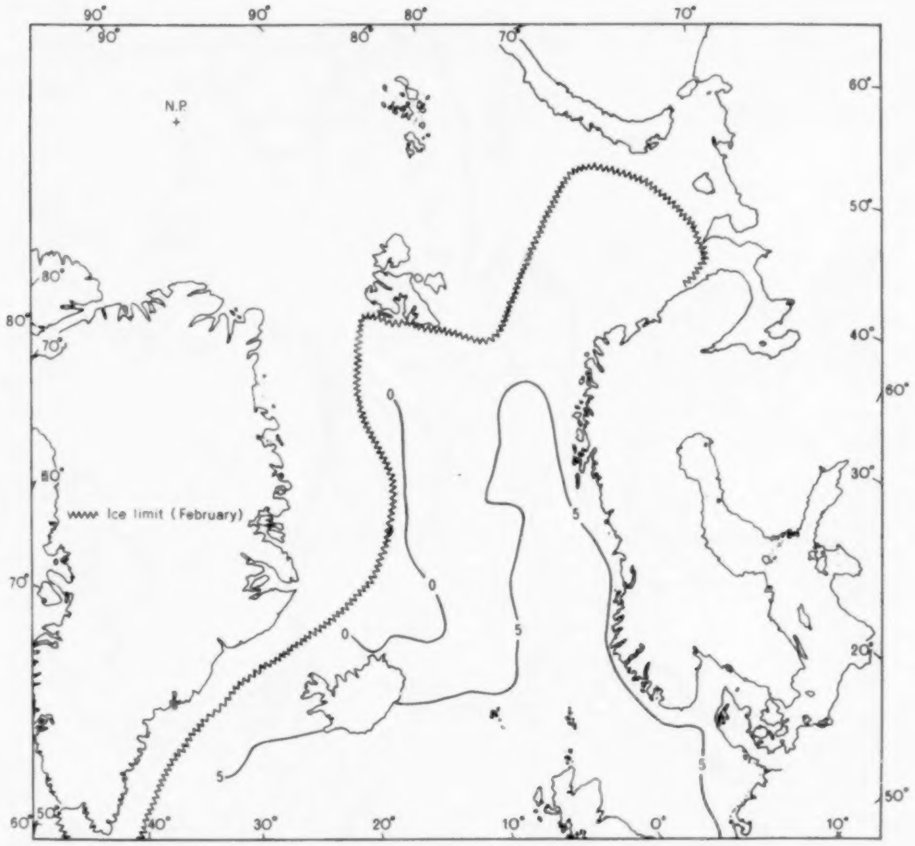
N.P.
Ice limit (February)
0
5
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°

Figure 3-XXVIII. Surface Temperature Distribution in February (°C) – Norwegian and Adjacent Seas

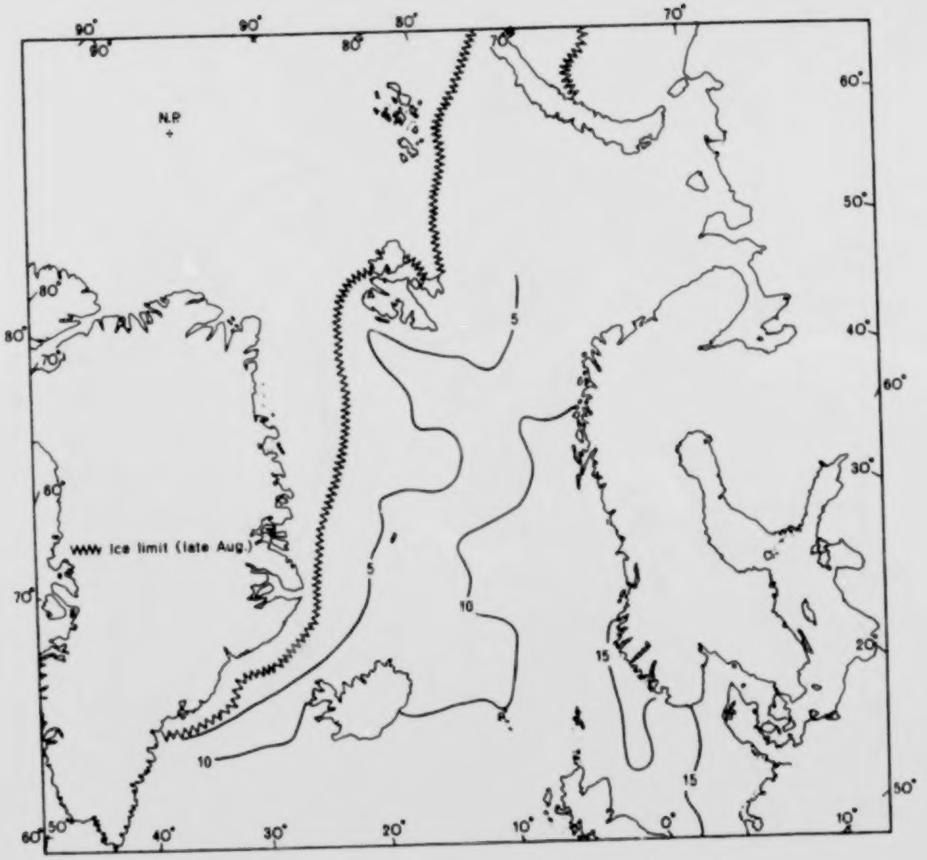
90°
90°
90°
80°
80°
70°
70°
60°
50°
40°
60°
30°
20°
50°
N.P
80°
80°
70°
60°
70°
60°
50°
40°
30°
20°
10°
0°
10°
ww Ice limit (late Aug.)
5
5
10
10
15
15

Figure 3-XXIX. Surface Temperature Distribution in August (°C) – Norwegian and Adjacent Seas

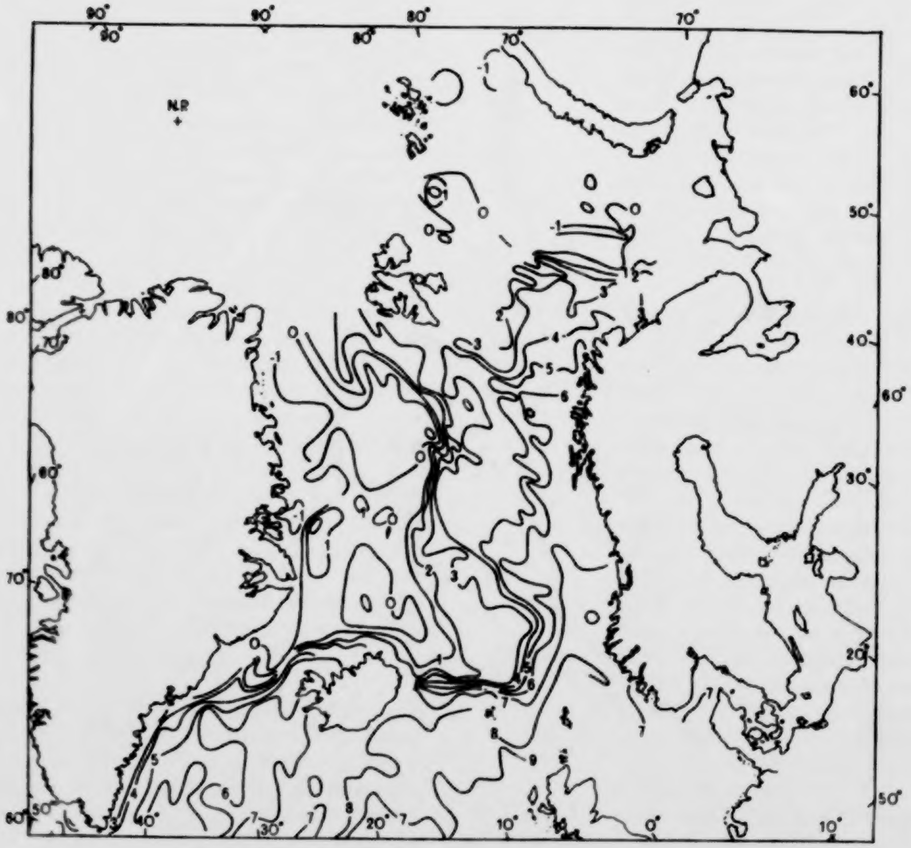
90°
90°
90°
80°
80°
70°
70°
N.P.
60°
50°
40°
60°
30°
20°
50°
80°
70°
80°
70°
60°
50°
40°
30°
20°
10°
0°
10°
-1
0
1
2
3
4
5
6
7
8
9

Figure 3-XXX. One Hundred Ten Fathom (201 m.) Temperature Distribution (°C) – Norwegian and Adjacent Seas

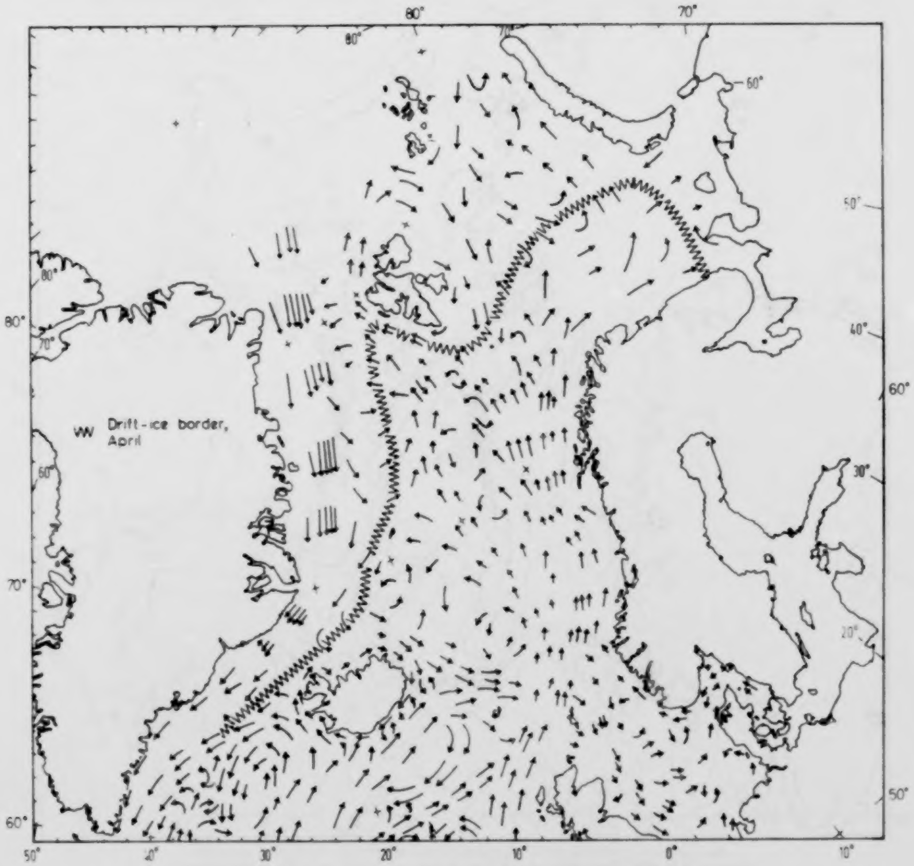
80°
70°
60°
50°
40°
30°
20°
10°
0°
Drift-ice border, April

Figure 3-XXXI. Surface Currents – Norwegian and Adjacent Seas

months (August) are given in Figures 3-XXVIII and 3-XXIX. The trends of the 110 fathom (201 m.) isotherm (see Figure 3-XXX) indicate the direction of the current speed; the steeper the gradient the greater the speed. A comparison of the 110 fathom (201 m.) isotherms with those for the surface in summer yields some indication of the amount of thermal stratification in the warm season, whilst comparison with those for winter shows the effect of the convective stirring of the water column brought about by winter cooling of the surface layer.

(2) The two dominant features are the warm currents which form the ends of the Gulf Stream system and the cold currents that derive from the North Polar Basin. Taking the warm currents first, the North Atlantic Drift divides at the Mid-Atlantic Ridge at about latitude 51°N. One arm moves northwards parallel to the Ridge towards Iceland where it becomes the Irminger Current. This latter carries the Irminger Atlantic Water and it bifurcates to the west of Iceland, one branch proceeding northwards and then turning east along the north coast of Iceland and the other turning first west and then south to flow along the East Greenland Slope eventually to round Kap Farvel and flow northwards along the West Greenland Slope in the Davis Strait.

(3) A second arm of the North Atlantic Drift carries warm Northeast Atlantic Water eastwards towards the British Isles and it passes through the Faroes-Shetlands Channel and to the west of the Faroe Islands into the Norwegian Sea where it is known as the Atlantic or Norwegian Current. This current moves northwards along the Norwegian coast and gradually becomes cooler and less saline as it does so. Off northwest Norway it divides into the North Cape Current, which flows eastwards into the Barents Sea, and the West Spitsbergen Current, which continues northwards past Vest Spitsbergen to enter the North Polar Basin where the Atlantic water forms an intermediate warm layer. Part of the West Spitsbergen Current turns westwards off the northern part of Vest Spitsbergen and flows towards the Greenland Shelf. It then turns south and proceeds below the East Greenland Current as a warmer, more saline, intermediate layer at 100 – 200 fathoms (183 – 366 m.) depth.

(4) The main cold current of the region is the East Greenland Current. This carries ice and Arctic water, with sub-zero temperatures and low salinity, from the North Polar Basin along the whole length of the East Greenland Shelf to round Kap Farvel and enter Davis Strait.There are two branches of the East Greenland Current: the first, the Jan Mayen Current, flows eastward to the north of Jan Mayen in the region of the Mohn Ridge whilst the second, the East Icelandic Current, flows southeastwards past the northeast coast of Iceland to sometimes reach the north coast of the Faroe Islands and beyond. A smaller source of Arctic water and ice are the Björnöya and East Spitsbergen Currents. These originate in the northeastern part of the Barents Sea and move southwestwards over the Svalbard Shelf, the former to reach Björnöya and the latter to round Sörkapp in Vest Spitsbergen and flow northwards between the Vest Spitsbergen coast and the West Spitsbergen Current. The distribution of the sea ice is determined by the East Greenland Current and its two branches and to a lesser extent by the East Spitsbergen Current. (Figure 3-XXXI.)

(5) Between the East Greenland Current and its branches on the one hand, and the Atlantic Current on the other, an effective mixing takes place and wide areas in the Norwegian and Greenland Seas are covered by mixed water (Figure 3-XXVII). Similar mixing on a smaller scale between warm and cold currents takes place on the Svalbard and Barents Shelves and along the East Greenland Slopes south of the Denmark Strait. Where the warm and cold currents meet, extremely sharp temperature gradients can occur in the near-surface layers. Coastal water of varied composition and temperature occurs along the coasts of Iceland and Norway, that off the coast of southern Norway being reinforced by low salinity Skagerrak water of Baltic origin. These coastal waters mix along the edges of the Norwegian and Icelandic Shelves with the warm currents that flow outside and beneath them.

(6) The speeds of the various currents are not well-established. There is evidence to suggest that there are frequent changes because of the wind. Some estimates put the speeds of the Atlantic Current and East Greenland Current at 12-24 nautical miles (22-44 km.) per day. Locally the East Greenland Current can reach very high speeds, for example 3 kt. (150 cm./sec.) just south of the Denmark Strait. The basins of the Norwegian and Greenland Seas contain a very nearly uniform deep water with a salinity of about 34.92°/oo and a temperature about -1°C. Seventy percent of the combined basins is below 300 fathoms (549 m.) depth and filled with this Norwegian Sea Deep Water. The mixed water in the upper layers, primarily in the Greenland Sea and to a smaller extent in the Norwegian Sea, is cooled in winter, but before it can freeze it reaches a higher density than that of water below it and so sinks to form the Deep Water. In the region of the Iceland-Jan Mayen and Mohn Ridges, Arctic Intermediate Water appears above the Norwegian Sea Deep Water and below the Arctic Water of the East Greenland Current system. It has its core at about 1,300 ft. (400 m.) depth and has a temperature between 0° and 2°C and a salinity between 34.8 and 35.0°/oo. It is formed by the cooling of Atlantic Water and mixing with the Deep Water and, to a lesser degree, Arctic Water. Further south in the Icelandic coastal area, vertical mixing of Atlantic Water and Arctic Water in winter results in a homogeneous water in the uppermost 100 – 200 fathoms (183 – 366 m.). This water has a temperature of 2-3°C and a salinity of 34.85-34.90°/oo and is called North Icelandic Winter Water.

(7) The Norwegian Sea Deep Water escapes into the North Atlantic Basin through the channel between Faroe Bank and the Faroe Islands. It flows at the bottom of this channel at a speed in excess of 2 kt. (100 cm. /sec.) and as it does so the Northeast Atlantic Water, which lies above it, is entrained into the flow. The resultant mixing produces the Northeast Atlantic Deep Water. This water mass has minor constituents because, at times, the Arctic Intermediate Water flows through the same channel and the Norwegian Sea Deep Water, Arctic Intermediate Water and North Icelandic Winter Water overflow the Faroes-Iceland Ridge, particularly near Iceland, proceed down its southern flanks, entraining overlying Northeast Atlantic Water as they do so, and eventually join the outflow from the Faroe Bank Channel as it flows westwards at the foot of the ridge.

(8) The Northeast Atlantic Deep Water eventually turns south when it meets the Reykjanes Ridge; at about

latitude 53°N it breaks through this ridge and flows northwards along its western flanks to fill most of the Irminger Sea at a depth of 950 – 1350 fathoms (1737 – 2468 m.). Above it, in the Irminger Sea, is Labrador Sea Water with its core at 300 – 700 fathoms (549 – 1280 m.). This water is formed as the result of the vertical mixing from the surface to 800 fathoms (1463 m.) depth of low salinity water in the Labrador Sea in winter. Below the Northeast Atlantic Deep Water in the Irminger Sea is the Northwest Atlantic Bottom Water which originates with the overflow of water from the Norwegian Sea across the Iceland-Greenland Ridge in the region of the narrow deep channel in the Denmark Strait. The overflowing water is at times Norwegian Sea Deep Water and at times Arctic Intermediate Water. In both cases the overflow proceeds at high speed down the East Greenland Continental Slope and entrains, first, overlying Irminger Atlantic Water and, later, Labrador Sea Water and Northeast Atlantic Deep Water to produce a water mass of high density which fills the bottom parts of the basins of the Irminger and Labrador Seas. Thus, in addition to there being a counterclockwise horizontal circulation in the upper part of the water column, with the Northeast Atlantic Water entering our area and the East Greenland Current leaving it, there is also a circulation in the vertical plane with the inflow of the Northeast Atlantic Water being compensated by deeper outflows, over the Scotland-Greenland Ridge, of Norwegian Sea Deep Water and Arctic Intermediate Water.

314. EURASIAN COASTAL WATERS

a. *Bathymetry*

(1) The Barents Sea occupies nearly a half-million square miles (1,400,000 sq. km.) on the continental shelf of Eurasia. It has free contact with the Norwegian Sea on the west and with the Arctic Ocean on the north, and it is deeper than the other peripheral seas, much of it being greater than 100 fathoms (183 m.) deep. The bottom is more like a continental borderland than a shelf, as it has both exceptionally shallow and deep areas scattered through it. The flat shelf areas are east and southeast of Svalbard and in the southeastern part of the sea. An east-west ridge at a depth of 100 fathoms (183 m.) connects the shore areas around Z. Frantsa Iosifa with Svalbard, and a north-south ridge at 160 fathoms (293 m.) separates the western Björnöya basin with depths of over 200 fathoms (366 m.) from the eastern basin. The eastern depression extends southwest between Z. Frantsa Iosifa and Novaya Zemlya with general depths over 150 fathoms (274 m.) and occasional depths over 200 fathoms (366 m.). In the extreme north there is a third depression between Svalbard and Z. Frantsa Iosifa.

(2) The White Sea is a large arm of the Barents Sea that projects more than 300 miles (500 km.) into the European mainland. The approach from the Barents Sea is appropriately called Voronka (Funnel), and is about 70 miles (110 km.) wide. The entrance narrows to the southwest until between the P-ov. Kol'skiy and the mainland it becomes a strait, called Gorlo (the Throat), 30 miles (50 km.) wide, where ice obstructs navigation even when the western, inland and wider part of the White Sea is reasonably ice-free. The White Sea is mostly less than 55 fathoms (101 m.) deep.

(3) The Kara Sea is exceptionally shallow in the east but relatively deep for its position on the continental shelf in the west. Off the east coast of Novaya Zemlya there is a

50 miles (80 km.) wide basin that in some places is 300 fathoms (549 m.) deep. A ridge in the north of the Kara Sea separates the basin from the Arctic Ocean. Between P-ov. Yamal and Novaya Zemlya there is another trough of deeper water. There are two more basins in the north of the sea, which have maximum depths of about 300 fathoms (549 m.) and are separated by a ridge. O. Uyedineniya, Vize and Ushakova form the highest elevations of this ridge. In the southeast of the Kara Sea depths average only 28 fathoms (51 m.) 60-150 miles (100-250 km.) from the shore. The water adjacent to the Ob' and the Yenisey rivers is also exceptionally shallow.

b. *Currents* (Figure 3-XXXII)

(1) The surface characteristics of both climate and sea ice in the Barents Sea result primarily from an influx of warm water from the Norwegian Sea. This warm current flows north along the coast of Norway; a southern branch enters the Barents Sea along the north coast of Norway and Kol'skiy P-ov. as the North Cape Current; the northern branch flows north of Björnöya and then turns northwest, passing along the south and west coasts of Svalbard as the West Spitsbergen Current. Off Varanger Halvöya, the North Cape Current flows at 8 nautical miles (15 km.) a day but the velocity decreases to the east. The current splits at Varanger Fjord; one part flows in a belt 50 – 60 miles (80-100 km.) wide to the entrance of the White Sea; the other curves northeastwards across the Barents Sea and passes north of Novaya Zemlya into the Kara Sea. This branch is weak in the north and south of its course, but between 36°E and 44°E it runs at approximately 18 nautical miles (33 km.) a day.

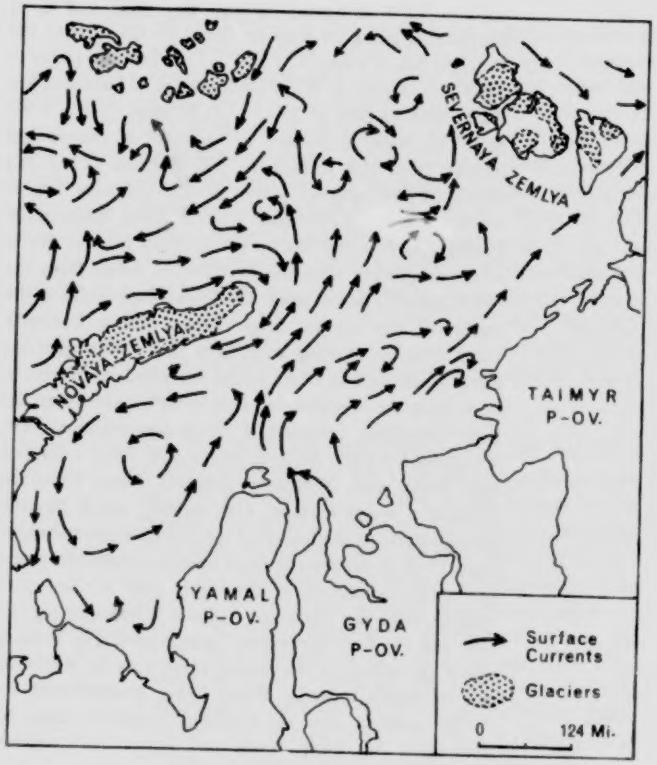

Figure 3-XXXII. Surface Currents – Barents and Kara Seas

(2) The major inflow of cold water into the Barents Sea is

between Novaya Zemlya and Z. Frantsa Iosifa. This current also branches into two parts: one part flows southwest of the archipelago and the other west as the Bear Island Current. In the southeast the general movement of water is towards the Kara Sea except for the Litke Current which has the reverse direction. It moves west through the northern half of P. Karskiye Vorota, and then northwest along Novaya Zemlya, joining the general northerly movement there. In the White Sea there is a weak outward current in spring and summer, and an equally weak counter-clockwise eddy within the basin.

(3) The only important current in the Kara Sea forms a closed counter-clockwise circulation in the west. The gyre begins in the east with Ob' and Yenisey waters which broaden as they leave the estuaries. One branch flows to Novaya Zemlya where it turns southwest to Proliv Karskiye Vorota. Within the main circulation are two small weak counter-clockwise eddies. Water also enters the Kara Sea around the north of Novaya Zemlya from the Barents Sea and eventually mixes with the Ob-Yenisey waters.

(4) Tides in the Kara Sea are semidiurnal and relatively weak. They come from the Barents Sea along eastern Novaya Zemlya and from the Arctic Ocean along western Severnaya Zemlya. They merge at O. Uyedineniya and progress southwest. The average amplitude is 1.5 to 3 ft. (0.5 to 1 m.). Winds commonly increase the tidal range by 3 ft. or more.

315. EASTERN SIBERIAN COASTAL WATERS

a. *Bathymetry.* Both the Laptev and the East Siberian Seas are shallow basins with gentle shores. The edge of the continental shelf is up to 500 miles (800 km.) offshore. Only in the northeast Laptev Sea, off Severnaya Zemlya, are depths greater than 50 fathoms (91 m.). The western sector of the East Siberian Sea south of the Ostrova Novosibirskiye and east to the Kolyma River, is exceptionally shallow with many shoals. Between the Indigirka and the Kolyma Rivers, an almost continuous shorebank, defined by the three fathom curve, extends about 27 miles (44 km.) out from the shore. From the Kolyma east to Mys Shmidta, the coastal water is deeper. There are only a few islands, and these, with the exception of Medvezh'i Ostrova, are close to the shore. The sea deepens slowly to the northeast; maximum depths are 25 – 30 fathoms (46 – 101 m.).

b. *Currents*

(1) The general flow of water in both the East Siberian and Laptev Seas is counter-clockwise. There is a weak, easterly coastal current which is modified by water from the large rivers which forces it offshore in a northeasterly direction at 1 kt. (2 km./h.); counter-clockwise eddies develop when it is caught in coastal indentations. The major current entering the Laptev Sea comes through Proliv Vil'kitskogo between M. Chelyuskin and Severnaya Zemlya. It is joined by a cold current flowing southeastward along Severnaya Zemlya at 0.2 kt. (0.4 km. /h.) and the combined waters move along the Taymyr' coast into the shallow part of the Laptev Sea. At the Lena Delta the current splits, one part, flowing along the west side of the Ostrova Novosibirskiye at 0.5 – 1 kt. (1 – 2 km. /h.), sets to the north of the archipelago and joins the main Arctic drift. The other part flows through Proliv Dmitriya Lapteva and other straits into the Eastern Siberian Sea.

(2) The waters that pass through the straits separating Ostrova Novosibirskiye and the mainland spread out on reaching the East Siberian Sea. The main branch near the coast flows at approximately 0.3 kt. (0.5 – 2 km./h.). A branch of this current is believed to pass north and west of Ostrov Vrangelya. In summer a current reaches through Bering Strait and flows northwest to the middle of Proliv Longa; its direction may be reversed in the winter.

(3) North of the coastal currents in both the Laptev and the East Siberian Seas, the water flows in large counter-clockwise eddies. Farther north still is a west-northwest current, which runs northwest at the Ostrova De-Longa and passes north of the Ostrova Novosibirskiye into the Laptev Sea. It continues northwest across the northern margin of the sea and flows north of Severnaya Zemlya.

(4) Tidal progression is southwards from the Arctic Ocean in both seas. Tides are semi-diurnal and their range is 1 ft. (30 cm.), although it may be raised to 10 to 12 ft. (3.0 to 3.5 m.) with an onshore wind. Tidal currents flow from 0.5 to 0.8 kt. (1 to 1.5 km. /h.) in the Laptev Sea, but are weaker in the East Siberian Sea.

316. CENTRAL POLAR BASIN

a. *Bathymetry and Submarine Topography*

(1) The Arctic Ocean is a true ocean. Beneath the deepest parts, the crust of the earth is about 10 km. thick, a figure that is fairly typical of the other oceans. The Arctic Ocean also shares with other oceans the characteristic that relief occurs at two predominant levels: the continental shelves with depths of a few hundred metres, and the deep basins with depths of several thousand metres. A sharp break in slope between the continental shelf and the continental slope marks the boundary between the shelves and basins, and defines the edge of the Central Polar Basin. In most oceans, the shelf break is at about 100 fathoms (183 m.) depth, but in the Arctic it is deeper in some localities (200 – 260 fathoms: 366 – 475 m.). First recognition that the Arctic Ocean was not a shallow sea but contained a true deep basin came from the soundings of the Norwegian North Polar Expedition during the drift of the Fram (1893-1896). The pack ice of the central Arctic cannot be penetrated by icebreakers and exploration has been conducted with aircraft, drifting ice stations, and nuclear submarines. Oceanographic research proceeded slowly after the successful voyage of the Fram and it has only been in the last two decades that renewed efforts by the U.S.A. and U.S.S.R. have resulted in our present level of understanding.

(2) Early bathymetric maps of the oceans usually showed smooth and unrealistic contours based on wire soundings. With the introduction of the continuous echo sounder, it became clear that the contours often cut across regions with quite different bottom characteristics. Recently there has been a trend to analyse the ocean floor in terms of physiographic provinces which cover areas of similar topographic textures and which contrast with surrounding areas. Almost all the various provinces found in other oceans, except deep-sea trenches, are known in the Arctic Ocean. The first-order features are the continental margins and the ocean basins. The continental margin is made up of the continental shelf, continental slope, continental rise, and marginal plateaux. The ocean basin consists of ridges,

rises, and abyssal plains. A map of the major physiographic provinces of the Arctic Ocean is shown in Figure 3-XXXIII.

b. *The Continental Margin*

(1) *Shelves, Slopes and Canyons.* The continental margin on the Eurasian side contains some of the broadest continental shelves in the world. The East Siberian Shelf is 300-550 miles (500-900 km.) wide and the Barents and Kara shelves are 450-750 miles (700-1, 200 km.) wide. In contrast the shelves off Greenland and northwest Canada are only 20-45 miles (30-70 km.) wide. North of Alaska the continental slope has a gradient (1:15 to 1:40) which is comparable to that in other parts of the world. In contrast the continental slope between the New Siberian Islands and the Chukchi Sea is apparently formed of several level surfaces and has been likened to a "giant staircase". Submarine canyons cut across continental shelves and slopes in the Arctic as in other oceans. Two prominent ones, Barrow Canyon and Herald Canyon, incise the Chukchi Shelf between Wrangel Island and Point Barrow. SSN Nautilus, during her 1958 Arctic cruise, made use of the deeper water of Barrow Canyon to cross the shelf below the ice. Many other canyons are known on the Canadian and Siberian continental shelves and slopes.

(2) *Rises and Plateaux.* A gently sloping continental rise usually lies at the foot of the continental slope. North of Alaska, this rise is 30 – 60 miles (50-100 km.) wide. Much greater widths of 200 – 300 miles (300-500 km.) occur in the continental rise off the Canadian Archipelago. A system of deep-sea channels with relief of 15 ft. (5 m.) crosses the Canadian continental rise. A marginal plateau is a level feature which borders the continental shelf at a greater depth. Several are known in the Arctic Ocean. The Chukchi Rise is crowned at its outer end by the Chukchi Plateau or Cap which has a flat summit with a diameter of about 60 miles (100 km.) at depths of 160 fathoms (293 m.). The surface is marked by a small-scale relief of 15-100 ft. (5-30 m.). Two submarine canyons indent the southwest side of the Plateau. Southeast of the Chukchi Plateau is an area of rough topography which has been described as a "continental borderland". Within this area is another plateau, the Northwind Cap. Other marginal plateaux include the Beaufort Terrace which, on its outermost edge, is similarly elevated above the saddle which connects to the continental shelf, and the Morris Jesup and the Yermak rises in the Greenland-Svalbard area.

c. *The Ocean Basin*

Lomonosov Ridge. The Central Polar Basin is crossed by three submarine mountain ranges. The ridges and rises are nearly parallel to one another and span the basin from the Eurasian to the Canadian side. A bathymetric profile (Figure 3-XXXIV) based on *SSN Nautilus* soundings, shows two of these ranges, the Lomonosov Ridge and the Alpha Cordillera. The Lomonosov Ridge, stretching 1,100 miles (1,800 km.) between the New Siberian Islands and the Greenland-Ellesmere Shelf, was discovered by Soviet scientists in 1948. It is a single continuous feature, 60 to 125 miles (100-200 km.) in width. Available echograms show a steep-sided ridge with a rather smooth profile. Minimum depth reported is 515 fathoms (941 m.). Saddles along the crest have depths of 830 – 880 fathoms (1518 – 1609 m.). A flat surface near the crest of the ridge has been noted on

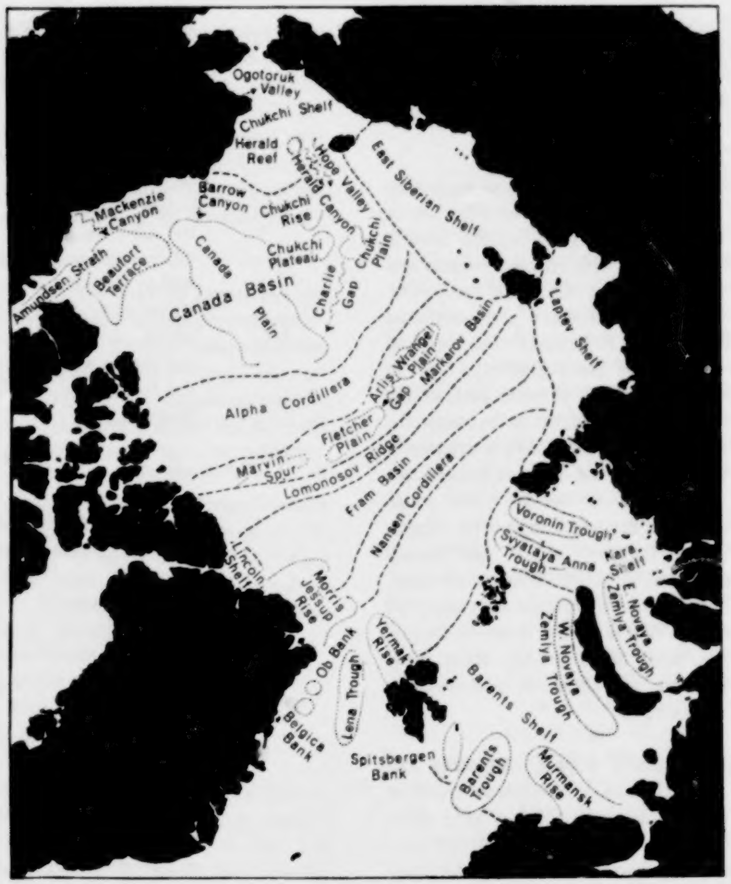
Ogotoruk Valley
Chukchi Shelf
Herald Reef
Hope Valley
Herald Canyon
East Siberian Shelf
Barrow Canyon
Chukchi Rise
Mackenzie Canyon
Chukchi Plateau
Chukchi Plain
Amundsen Strath
Beaufort Terrace
Canada
Canada Basin
Plain
Charlie Gap
Laptev Shelf
Arlis Gap
Wrangel Plain
Markarov Basin
Alpha Cordillera
Fletcher Plain
Marvin Spur
Lomonosov Ridge
Fram Basin
Nansen Cordillera
Voronin Trough
Svyataya Anna Trough
Kara Shelf
Lincoln Shelf
Morris Jessup Rise
E. Novaya Zemlya Trough
W. Novaya Zemlya Trough
Yermak Rise
Ob Bank
Lena Trough
Barents Shelf
Belgica Bank
Spitsbergen Bank
Barents Trough
Murmansk Rise

Figure 3-XXXIII. Physiographic Regions of the Arctic Ocean and Adjacent Seas

two different crossings. An offshoot of the Lomonosov Ridge is known as the Marvin Spur.

(2) *Other Ridges.* The Alpha Cordillera is about the same length as the Lomonosov Ridge but it is much broader, ranging from 155-500 miles (250-800 km.) in width. The crest of the Cordillera is 830 – 1080 fathoms (1518 – 1975 m.) deep. Topography is much rougher than that of the Lomonosov Ridge. The magnetic fields over these two features also differ. The field over the Alpha Cordillera is rough, with many anomalies exceeding 1,000 gammas, while there is little disturbance over the Lomonosov Ridge. Neither of these ranges is seismically active. The Nansen Cordillera is an extension of the Mid-Atlantic Oceanic Ridge into the Arctic Ocean. Where the topography has been sampled, it is rough, as it is on the Mid-Atlantic Ridge. The most distinctive characteristic of the Nansen Cordillera is the narrow earthquake belt along its crest (Figure 3-XXXV). The belt of earthquake epicentres crosses Iceland and then changes direction abruptly north of the island, where a large east-west fracture zone intersects the mid-oceanic ridge near Jan Mayen Island. Between northeastern Greenland and northern Siberia, the earthquake belt is narrow and straight for a distance of over 1,250 miles (2,000 km.). Within Siberia, the earthquake zone spreads out and disappears. In the Atlantic a similar earthquake belt coincides with a central rift valley at the crest of the mid-oceanic ridge. Although this relationship might be expected to hold in the Arctic, insufficient evidence has been collected for definite verification.

(3) *Abyssal Plains.* These are the ultimate repositories for sediments which have been transported across the continental shelves and down the continental slopes via the submarine canyons. In the deep basins the sediments collect to form the most extensive level surfaces on the globe, with gradients of 1:1,000 or less. Four of the abyssal plains in the Arctic Ocean are arranged in step-like pairs. Each pair is connected by an abyssal gap through which sediments are transported from the upper to the lower plain. The Canada and Chukchi Abyssal Plains are connected by the Charlie Gap. The complete route of sediment flow is from Herald Canyon to the Chukchi Abyssal Plain and then through Charlie Gap to the Canada Abyssal Plain; Wrangel and Fletcher Abyssal Plains are connected through Arlis Gap. Abyssal gaps are commonly named after the ship of discovery. In this case, the discovering "ships" were drifting ice stations, Charlie and Arlis, respectively. Seismic reflection profiles show that a prominent sub-bottom basement ridge exists in the vicinity of Arlis Gap. This ridge seems to have acted as a bedrock dam for the sediments of Wrangel Abyssal Plain, ponding them behind it until there was sufficient accumulation to spill over into Fletcher Abyssal Plain. Sediments move from the Siberian Shelf to Wrangel Abyssal Plain and then through Arlis Gap to Fletcher Abyssal Plain. A system of interplain channels funnels the flow across the plain and into the gap. The right bank of these channels is higher than the left bank, apparently due to the influence of the earth's rotation.

(4) The most extensive of these plains in the Arctic Ocean is the Canada Abyssal Plain which covers an area of 98,000 sq. miles (254,000 sq. km.). It is remarkably flat, with depths ranging from 2060 fathoms (3768 m.) in the north to 2100 fathoms (3841 m.) in the south. On its northern and western edges it is bounded by the scarps of the Alpha Cordillera and Chukchi Rise. The eastern and southern boundaries grade smoothly into the con-

tinental slope. The Pole Abyssal Plain is deeper than the four plains previously mentioned. In the neighbourhood of the North Pole it is flat and smooth with a depth of 2233 fathoms (4084 m.). Away from the Pole the depth of the plain increases to 2500 fathoms (4572 m.).

d. *Bottom Sediments*

(1) Light brown foraminiferal oozes are generally intermixed with sands and gravels on elevated topography such as ridges and rises. This is known as a glacial marine sediment. The ooze represents normal pelagic sedimentation. The sands and gravels are ice-rafted material which has been carried out from shore on ice floes and ice islands to be dumped when the ice melted or broke up. Rocks are often observed strewn over the bottom in deep-sea photographs. The unsorted ice-rafted rocks range greatly in size. A cobble weighing over 15 pounds (7 kg.) has been dredged. In bottom photographs, rocks with dimensions of about one metre have been seen. These rocks show faceting and striations which are typical of glacial deposits. On the ridge and rise areas, sedimentation is extremely slow, only a few millimetres accumulating in 1,000 years. Thus many thousands of years are required to bury an ice-rafted rock. Signs of bottom life are rare in these regions.

(2) Sediments on the Canada Abyssal Plain are greyer in colour and lack the ice-rafted debris found on the elevated areas. The sediments of the abyssal plains presumably also contain the pelagic and glacial components but these have been inundated and diluted by turbidity current deposits. Turbidity currents originate on continental slopes when oversteepened sediments slump and flow down submarine canyons as a slurry of mud and water. They flow and spread out on reaching the abyssal plain, depositing the mud over the level surface. The coarsest material settles first so that the beds are usually graded. No rocks are found in photographs taken on the Canada Abyssal Plain. Signs of animal life, such as intricate patterns of tracks and burrows, are abundant.

(3) Seismic reflection profiles give a thickness of about one kilometre for the unconsolidated sediments near the northern edge of the Canada Abyssal Plain. The thickness must be greater near the centre of the plain. The same technique has shown at least 2 miles (3.5 km.) thickness of nearly horizontally stratified sediments underlying Wrangel Abyssal Plain. The layer of unconsolidated sediment is much thinner on the ridges and rises. Measurements on the Alpha Cordillera generally give thicknesses between 1,000 – 1,600 ft. (300-500 m.).

e. *Currents.* In simplest terms, the Arctic Ocean may be considered as a polar estuary of the Atlantic. In high latitudes, water temperatures are always near the freezing point and salinity is the controlling factor in water density. Warm saline water from the Atlantic enters the Arctic Ocean northwest of Svalbard where its greater density causes it to sink beneath the surface. It then spreads throughout the Arctic Ocean at the level appropriate to its density. This water loses its heat and salinity as it mixes upward with the surface waters, which are cooled by loss of heat to the atmosphere and freshened by precipitation and river run-off. The surface water then flows southward, out of the Arctic Ocean, as the East Greenland Current. This estuarine circulation is modified by the winds. There is also a weaker intrusion of warm saline water from the Pacific Ocean.

f. *Water Masses.* Four water masses are recognized in the Central

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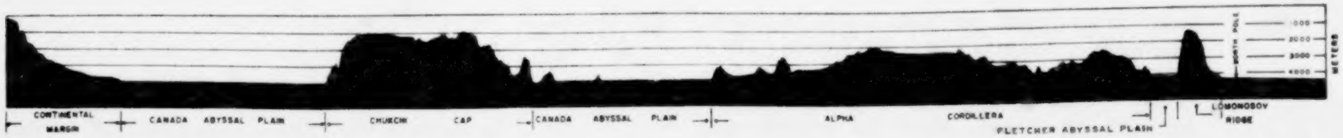

Figure 3-XXXIV. Topographic Profile Across the Arctic Ocean

Polar Basin:

(1) The Arctic surface water lies between the surface and a depth of 110 fathoms (201 m.). Salinity may be as low as 30° /oo in this layer at the surface, but it increases rapidly below 30 fathoms (55 m.). Temperature is generally close to the freezing point.

(2) On the Alaskan-Canadian side of the ocean, there is a small temperature maximum (-0.7°C) at about 40 fathoms (73 m.) which is known as the Pacific Water. The temperature maximum decreases with distance from the Chukchi Shelf.

(3) The Atlantic water is marked by positive temperatures between 110 – 500 fathoms (201 – 914 m.). Salinity increases with depth in this layer until, at about 200 fathoms (366 m.), relatively uniform salinities of 34.9 to 35.0° /oo are attained. The depth of the maximum temperature in the Atlantic layer increases with distance from its source northwest of Svalbard. It is initially at 160 fathoms (293 m.) but increases to 280 fathoms (512 m.) north of Alaska. The temperature maximum decreases with distance from Svalbard from an initial value of 3°C to 0.5°C north of Alaska.

(4) Arctic Deep Water lies between the Atlantic Water and bottom. Temperatures are below 0°C and salinities increase very slowly with depth from 34.93 to 34.99° /oo. Below 750 – 830 fathoms (1371 – 1518 m.), the temperatures are 0.5°C warmer on the Canadian side than on the Eurasian side. These deep waters are presumably formed during cold winters in the Norwegian Sea. They first enter the basin on the Eurasian side of the Lomonosov Ridge. Some of the water flows over the saddles in the Lomonosov Ridge to form the warmer bottom water of the Canadian side.

g. *Tides.* Tides in the Arctic Ocean are small. For example, the mean spring tide range at Point Barrow, Alaska, is only 6 in. (15 cm.). The semi-diurnal tide is derived almost entirely from the Atlantic. It enters the Arctic Ocean between Svalbard and Greenland, travelling across the Arctic Ocean in about 12 hours as a progressive wave. On the Siberian shelves the tidal currents usually rotate clockwise. Storm surges may exceed the height of the tides and can cause damage to low-lying Arctic coasts.

h. *Underwater Sound*

(1) The propagation of underwater sound in the Arctic Ocean differs in several ways from that in non-polar

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oceans. In the Atlantic and Pacific Oceans, the SOFAR channel lies at depths of 550 – 750 fathoms (1005 – 1371 m.), but in the Arctic is at the surface. Low-frequency sound is propagated to great distances in the Arctic SOFAR channel. Sound rays are alternately refracted upward in the water and reflected downward from the base of the ice. At great ranges signals consist predominantly of low frequencies, 8-100 cps. Roughnesses on the lower surface of the ice strongly attenuate the high frequencies but have a negligible effect on the low frequencies. Signals generated by small explosions have been recorded clearly at distances from 50 miles up to about 1,850 miles (80-3,000 km.). Beyond a range of 350 miles (600 km.), waves above 100 cps are very weak. The Arctic SOFAR signal is dispersed so that an impulsive signal increases in duration as the range is increased. At a range of 350 miles (600 km.) the duration of a signal from a small explosion is about five seconds. At shorter ranges, and over smooth bottoms such as abyssal plains, bottom-reflected arrivals can be of importance. They are late arrivals and increase still further the duration of the signal.

(2) In the shallow water of the shelves, propagation characteristics depend strongly on bottom parameters. In general, long-range transmission is much more strongly attenuated along shallow water paths than it is along deep water paths. Dispersion is even more pronounced in shallow water transmission. A shallow sound-scattering layer has been observed beneath the central Arctic Ocean during the summer months. This scattering layer appears on echograms made at a drifting station with a 12 cps sounder.

(3) Information on the sound velocity structure of the ocean can be obtained from measurements of temperature, salinity and depth. For very precise measurements of these factors at specific depths, Nansen bottles and reversing thermometers are employed. Information thus obtained can be converted into sound velocity by various methods. Representative examples of sound velocity structures in the Greenland Sea are shown in Figure 3-XXXVI.

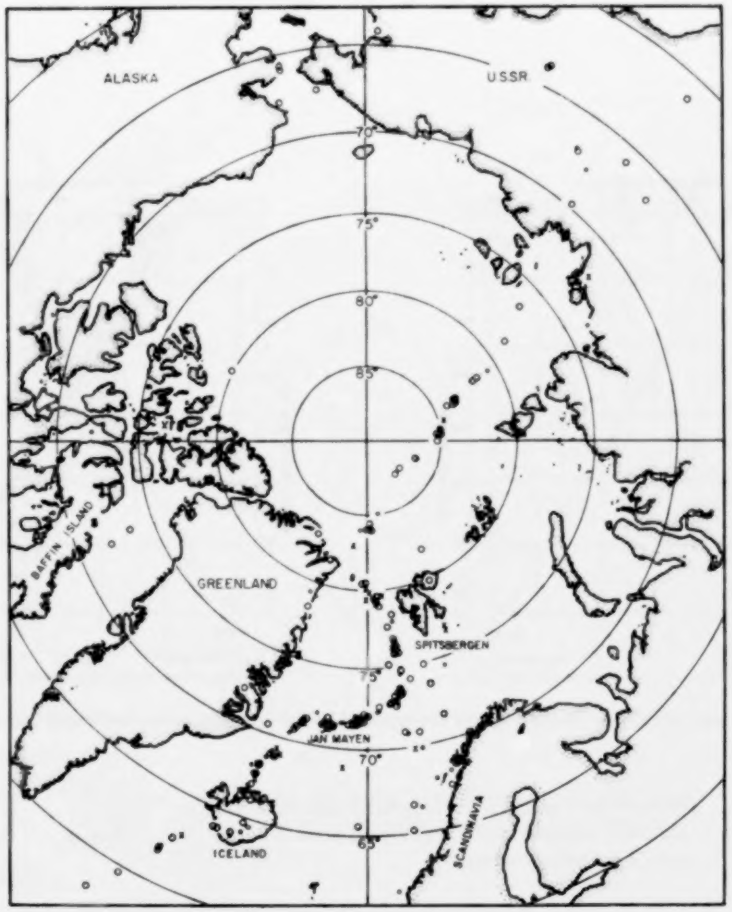
ALASKA
U.S.S.R.
70°
75°
80°
85°
BAFFIN ISLAND
GREENLAND
SPITSBERGEN
75°
JAN MAYEN
70°
ICELAND
65°
SCANDINAVIA

Figure 3-XXXV. Earthquakes in the Arctic, January '55 – March '64.

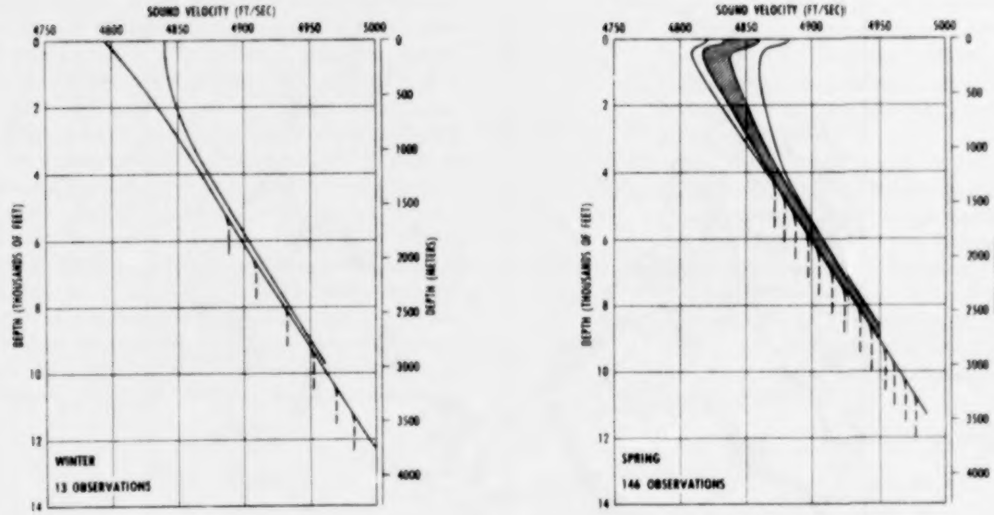

Figure 3-XXXVI. Representative Examples of Sound Velocity in the Greenland Sea

Dashed lines represent the individual observations within total given that show negative sound velocity gradients resulting from extremely cold Arctic bottom water.

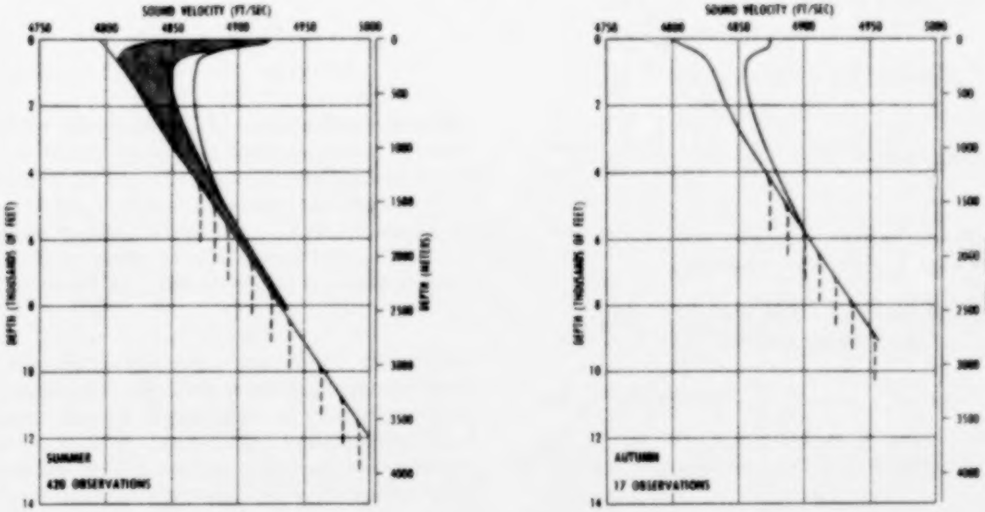

Figure 3-XXXVI (Cont'd). Representative Examples of Sound Velocity in the Greenland Sea

Dashed lines represent the individual observations within total given that show negative sound velocity gradients resulting from extremely cold Arctic bottom water.

CHAPTER 4

SEA ICE

SECTION I – GENERAL DESCRIPTION

401. INTRODUCTION

a. Sea ice is mainly a phenomenon of higher latitudes, but in winter and early spring it extends down the east coast of Asia and of North America over half way to the Equator. It is always the dominant factor in polar operations by sea, as thin-skinned ships can enter northern waters only during the break-up period. Sea ice is also seasonally an extremely important factor governing marine operations in temperate latitudes, for most of this ice has sufficient strength to present a hazard to shipping.

b. In describing the nature and behavior of any natural phenomenon it is important to define the terms which are used. There is then some assurance that the interpretation of information will be uniform and close to what is intended. The World Meteorological Organization (WMO) has done much work in ice definitions and in standardizing the terminology used in describing sea ice and the codes for reporting it. This organisation is currently working towards uniform charting methods and will shortly publish an illustrated Glossary. The W.M.O. ice terminology and descriptions (revised and expanded in 1968) are provided in this chapter (see Article 409). Pertinent photographs of types of ice are also presented (see Figures 4-IV to 4-XIII).

c. Ice in the sea can vary in thickness, concentration, arrangement and location. All these factors have an effect on Arctic seaborne operations, and uniform and accurate reporting of sea ice conditions is essential for planning and operational purposes.

d. *Thickness.* Thickness, stage of development or age of ice refers to a process which occurs in four stages:

(1) New ice which is unconsolidated crystals to nilas, a thin flexible grey layer.

(2) Young ice – a grey or grey-white layer up to 12 inches (30 cm.) thick.

(3) First year ice – floes of not more than one winter's growth and more than 12 inches (30 cm.) thick.

(4) Old ice of two or more years growth and generally about 9-10 feet (3 m.) in thickness.

e. *Concentration*

(1) The amount of ice is termed "concentration" and is reported in tenths or eighths:

(a) 1-3/10 (1-2/8) is termed very open pack.

(b) 4-6/10 (3-5/8) is open pack.

(c) 7-8/10 (6/8) is close pack.

(d) 9 to less than 10/10 (7/8) is very close pack.

(e) 10/10 ice (8/8) may be termed compact ice or, if the floes are frozen together, consolidated ice.

(2) Floe size ranges from ice cakes (6-30 feet: 2-10 metres in width) through small, medium, big, and vast to giant floes which are over 6 nautical miles (10 km.) in width.

(3) When the floes are pressed together, the process is termed "rafting" if one floe over-rides another with little fracturing; "ridging" if a tent-shaped line of broken fragments is formed across the floes, and "hummocking" when random disconnected piles of fragments develop.

f. *Arrangement.* The descriptive terms used to indicate the arrangement of ice are mainly self explanatory, and include "bight", "tongue", "strip", "diffuse ice edge", "compacted ice edge", etc. Puddles can develop on the floes from melt water and are termed "thaw holes" if they penetrate through the bottom of the ice to the sea. "Crack" and "fracture" are used in their normal sense, but if the floes separate sufficiently to permit passage of ships, the opening is termed a "lead". A non-linear opening is a "polynya". Further details may be found in Article 409.

402. ICE FORMATION

a. The density of pure water increases as it is cooled until it reaches a temperature of 4°C; thereafter its density decreases to the freezing point. When a freshwater lake is cooled in autumn this results in vertical mixing, as the surface becomes more dense than the sub-surface layers. The process will continue until the lake reaches 4°C throughout its depth, and then only the surface layers are chilled until ice is formed. In a saline solution, the temperature of maximum density becomes lower as the amount of salts increase. The same is true of the freezing point, but its rate of lowering is somewhat slower. As a result, a point will be reached where the temperature of maximum density occurs at the freezing point (Figure 4-I).

b. Sea water contains many dissolved salts, but the proportions of each are sufficiently uniform that a single parameter "salinity" can be used to describe the amount contained. It varies from about 35°/oo (parts per thousand) in tropical waters to about 32°/oo in Arctic waters. Referring to Figure 4-I, the point where maximum density occurs at the freezing point is 24.7°/oo and a temperature of −1.3°C. All the oceans of the world have greater salinity than 24.7°/oo, so that sea water, when cooled, increases steadily in density until the freezing point is reached. Certain enclosed areas such as James Bay and the Baltic Sea have salinities too low for this to be true and they behave more like fresh water than salt water.

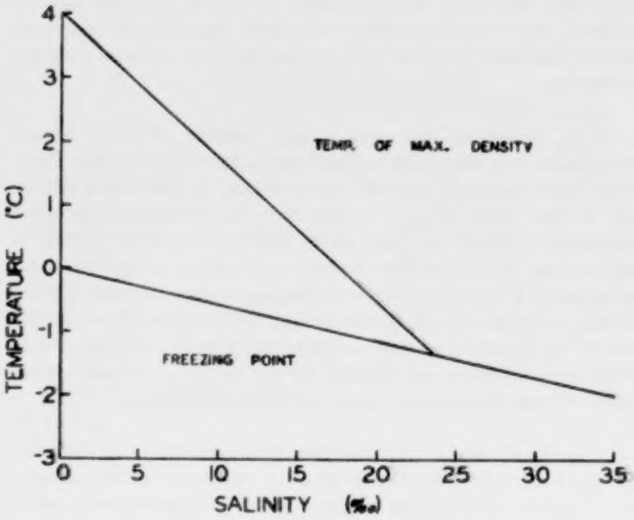

Figure 4-I. The Formation of Sea Ice

c. The significance of these facts relates to the vertical circulation set up in sea water when it is cooled by coming into contact with cold air. As the surface water is cooled, it contracts and sinks, being replaced by warmer and lighter water at the surface. The cooled water may penetrate downward until it reaches the sea bottom. In consequence the entire body of water must be cooled to the freezing point (− 1.7°C for water of salinity 32°/oo) before sea ice can form.

d. In practice, the oceans are usually somewhat stratified, with different temperatures and salinities at each depth. Despite these variations, the water must be basically stable and its density must increase with depth otherwise vertical currents will develop to correct this anomaly. Cooled surface water will thus sink to a level where the density of the surrounding water is the same as its own, rather than to the bottom as in the simple case cited in para c. A large volume of water must thus be cooled to the freezing point, but not often the entire ocean depth. This factor combined with the difference in temperature of maximum density is the reason for the delayed formation of coastal sea ice in comparison to nearby inland waters.

e. Ice has a crystal structure which is intolerant of impurities such as the inorganic salts which make up most of the dissolved material in sea water. If sea water is frozen very very slowly a cover of pure ice will form with impurities being rejected into the water below the ice. Natural freezing is never this slow however, and sea ice always contains a certain amount of entrapped salts. The actual amount is mostly dependent upon the freezing rate, but typical sea ice has a salinity of 4-6°/oo, 80-90% of the salt being excluded from the ice. The presence of this small proportion of salt has an extremely important effect on the physical properties of the ice.

403. STRUCTURE AND PROPERTIES OF SEA ICE

a. When sea water is cooled to its freezing point and more heat is removed, ice forms initially as very thin disks or platelets known as frazil ice. These platelets average 2-3 mm. in width and about 0.5 mm. in thickness but vary considerably in shape from hexagonal "snowflakes" to almost square plates. As further heat is removed these pure ice crystals grow and multiply. They are less dense than water so they float to the surface and give the water a slightly oily appearance (grease ice). Further cooling results in growth of the ice crystals and mechanical entrapment of small brine cells between them. Ultimately these cells become separated from the water below the ice by selective downward growth of the ice crystals.

b. The physical properties of sea ice are almost entirely dependent on its salt content. The detailed crystal structure which results dominates these properties to the extent that one can relate any of them to "brine volume". The brine volume is defined as the fraction of the volume of sea ice occupied by fluid (liquid brine or air bubbles).

c. Even fresh ice is an inhomogeneous material with varying crystal sizes and orientations, so all strength measurements show a great scatter of results and statistical methods must be employed to get averages of any validity. Another complicating factor is that ice readily undergoes plastic flow so that results vary with rates of stress. On the average, with rapid stress application at −5°C, the ultimate strength of fresh-water ice is 15 kg./cm.^{2} in tension, 7 kg./cm.^{2} in shear, 17 kg./cm.^{2} in flexure and 35 kg./cm.^{2} in unconfined compression. In dealing with sea ice these values should be adjusted by the formula,

$$\sigma = \sigma_0 (1 - 1.9\nu),$$

where σ_0 is the strength cited above for fresh ice and ν is the brine volume.

d. The response of ice to a rapidly varying force is elastic unless crushing occurs. Sound transmission, response to moving vehicles, and impact from landing aircraft all fall into this category; but deflections from static or slowly varying loads do not, for, in these cases, ice flows plasticly. Although this plastic flow has been studied in glaciers, little data is available on sea ice.

e. As cited above, sea ice contains cells of liquid brine at most naturally occurring temperatures, so any temperature change involves the melting of some ice or the freezing of some water. It is customary to include this latent heat effect as part of the specific heat of sea ice, and as a result the coefficient is strongly dependent upon the temperature and salinity of the ice.

f. Sea ice transmits acoustic energy readily, particularly at low audio frequencies, and bathymetric observations can be made through an ice cover by bonding a flat transducer to the sea ice surface with a thin film of non-freezing liquid. Reflection at the sea ice – water interface is small.

404. ANNUAL ICE CYCLE

a. The process of ice formation has been discussed in some detail in Article 402, but this is only the initial stage of ice growth which is always dependent upon heat loss from the sea. This heat must flow upward through the ice layer and through any snow lying on the ice so that the insulating qualities of these two materials are important factors in determining the rate and amount of ice growth. Air temperature and the amount of radiant energy falling on the surface are also important factors.

b. In the Arctic, radiation is almost completely dominant in determining the ice surface temperature and hence the duration of ice growth. This will continue until some time in spring when the increasing solar radiation changes the heat budget of the ice from a loss to a gain. This usually happens before the air temperature rises above the melting point of the snow cover. Pure white snow reflects as much as 90% of the radiation falling on it, and although the quantity of heat absorbed by the ice is small at first, the 24 hours of daylight and cloudless skies soon result in a gradual increase in the temperature of the ice. When the air temperature reaches the melting point, the snow surface begins to melt rapidly; it absorbs about 60% of the radiant energy and puddles of melt water become very extensive.

c. In temperate latitudes, the air temperature can contribute to the change from heat loss to heat gain by the ice, for it can rise above the melting point for appreciable periods, if only in the daytime. The situation is thus more complicated but the reversal of heat flux is still the controlling factor.

d. Puddling is the first apparent stage of deterioration of the ice cover. The water surface absorbs heat readily, permitting the puddle to widen and deepen and also to warm the ice. Later flaws and cracks develop in the floe through which much of the surface water drains away leaving dry hummocks of ice separated by ponds and streams of melt water. When the ice has this appearance operations on it must be carried out with caution for the bearing strength is uncertain and a wind can cause it to break up rapidly.

e. In temperate latitudes the ice is reduced to a grey, water-saturated matrix (rotten ice) which finally melts and the cycle is complete. Farther north, the summer is too brief for complete melting to take place and by late August or September puddles begin to freeze and new ice forms between the floes. After a time the floes themselves start growing again. A floe formed in one year which survives through the following summer differs chemically and physically from ice that is less than one year old. During the summer most of the brine drains out of the ice so that the typical salinity of old ice (second or multi-year ice) is about 0.5 to 1.0°/oo. Melt water from this ice is quite potable. The crystal structure of the ice becomes less regular, the crystals themselves are smaller and the ice is extraordinarily tough, even in summer.

f. In summer, old floes may be distinguished from first year ice by their color. The melt water puddles on an old floe have a very characteristic pale blue color which persists after they freeze. On first year ice, these puddles have a green to brownish appearance. The old ice itself has a pale blue color whereas first year ice is much more a greenish white color. The surface of first year ice is comparatively smooth except for pressure ridges and hummocks. Old ice has a characteristic uneven surface as a result of the differential melting of puddles and old hummocks.

405. OCCURRENCE OF SEA ICE

a. Ice in the sea can only be properly considered on a regional basis (see Section II of this chapter), for not only is its seasonal variation considerable, but also cold or warm ocean currents and weather systems have a very marked effect. Ice forms every winter in the Gulf of St. Lawrence in latitude 46-50°N for example, whereas the Norwegian coast from 60-70°N latitude is ice-free. In general cold, south-flowing currents on the east coast of North America and Siberia permit ice formation as far south as latitude 45°N and water currents may carry it even farther south in early spring. A similar flow carries ice down the east Greenland coast to Cape Farewell, but rather than moving south from there it continues into the coastal water of west Greenland and may penetrate as far north as Gothaab.

b. Mean maximum thicknesses of undisturbed ice in some of these areas are as follows: Gulf of St. Lawrence 3 ft. (1 m.); Hudson Bay and Baffin Bay 5 ft. (1.5 m.); Parry Channel and Beaufort Sea 6-7 ft. (2 m.) for first year ice, 10-12 ft. (3.5 m.) for old ice; Bering Sea 3 ft. (1 m.); east Greenland coast 10-12 ft. (3.5 m.) for old ice; Barents Sea 5 ft. (1.5 m.). Pressure ridges and rafted ice may be much thicker than these means, but there is little accurate data. Ridge heights of 13-16 ft. (4-5 m.) are common in the Arctic Ocean, and some of 25-35 ft. (8-10 m.) are also seen. In the adjacent seas, although the ice is slightly thinner, the effect of the island coasts is thought to result in similar ridging. Because of its density sea ice floats with 87 percent of its volume below the waterline, and there must, therefore, be a downward projection below each ridge or hummock (termed "ice keels" and "bummocks"). The actual geometry of these features has not been examined in detail, but submarine observations show a height/draft ratio of 1:4 or 1:5 rather than 1:7 as was first thought. It should be noted that only part of this downward projection will be frozen together and most of it will be a mass of fragments held in position by its buoyancy.

c. In summer the ice melts completely in the more southern areas such as the Sea of Okhotsk, Bering Sea, Hudson Bay, Labrador Sea and Baltic Sea, and large areas north of the Arctic Circle can be penetrated with care by conventional shipping. Baffin Bay and Lancaster Sound, Foxe Basin, Barents Sea and parts of the Chukchi and Beaufort Seas fall into this category, but year-to-year variations can be quite significant. Above latitude 75°N, break-up is very limited in the best of seasons and most operations are restricted to icebreaker class vessels.

d. Regional ice conditions are described in some detail in Section II of this chapter, and a series of ice coverage diagrams showing average winter and summer conditions in the Arctic Ocean and its peripheral seas has also been provided (see Figures 4-XX to 4-XXVIII). Ice Atlases and sailing directions should be consulted for detailed operational planning purposes.

406. ICE FORECASTING

a. The date of freeze-up of the sea depends on both the oceanographical and meteorological regimes encountered in the area. Only rarely are the knowledge of water currents and of the actual temperature-salinity variations with depth available for forecasts of this type to be made. The rate of ice growth on the other hand can be predicted with fair accuracy from meteorological data, as can the maximum thickness which will be obtained. It is much more difficult to predict rates of decay, for the process is slow and long range predictions of both wind and cloudiness are required for accurate results.

b. The most important forecasting problem is that of ice movement. The general pattern of ice movement in the Arctic Ocean is indicated in Figure 4-II. Although the ice cover remains landfast and

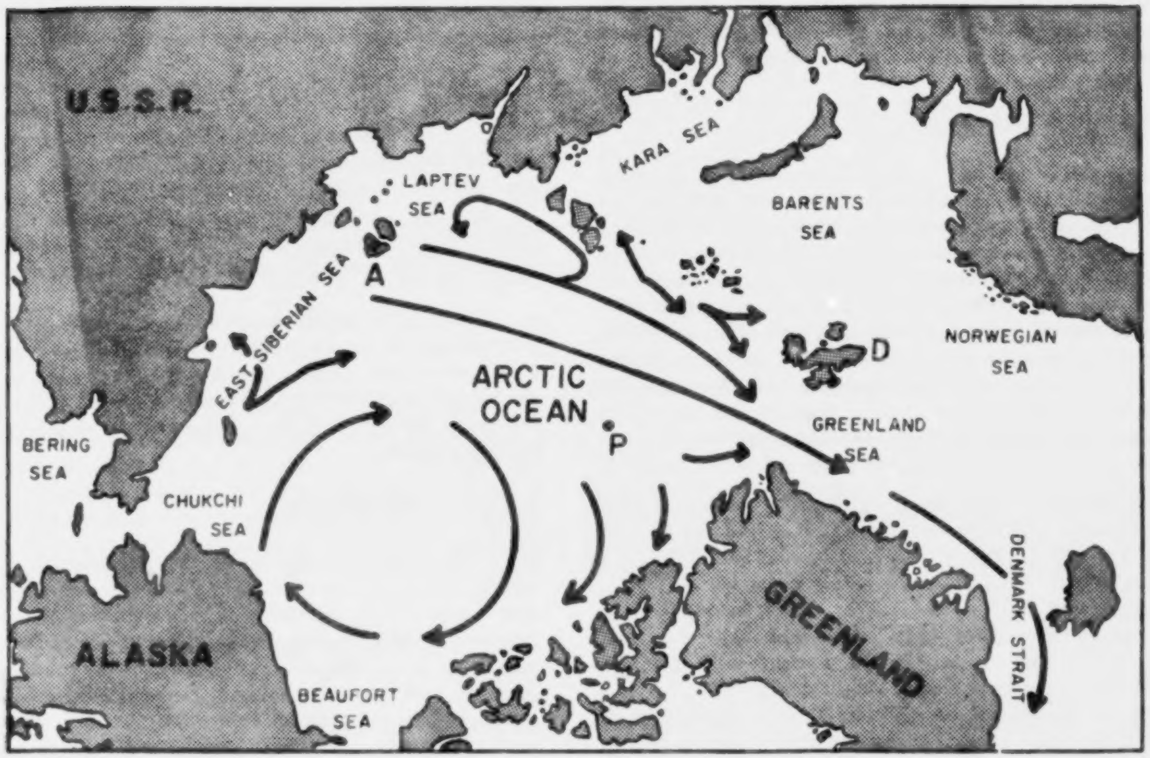
U.S.S.R.
LAPTEV SEA
KARA SEA
BARENTS SEA
EAST SIBERIAN SEA
A
D
NORWEGIAN SEA
ARCTIC OCEAN
P
GREENLAND SEA
BERING SEA
CHUKCHI SEA
DENMARK STRAIT
GREENLAND
ALASKA
BEAUFORT SEA

Figure 4-11. The General Pattern of Ice Movement in the Arctic Ocean

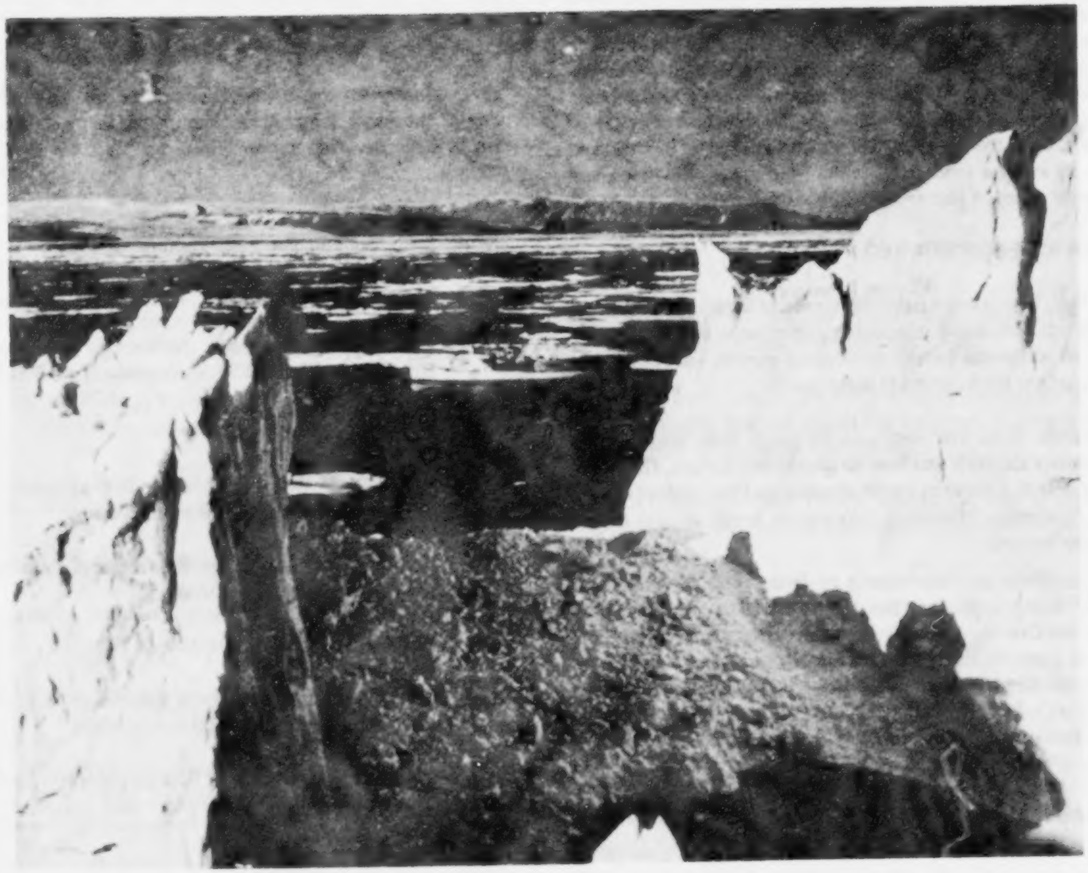

Figure 4-III. Freshwater Ice from a Glacier (Iceberg) (in Foreground)

motionless in narrow or island-studded channels throughout the winter, in the larger waterways and in the marginal seas this is not the case. The forces of wind drag, tide and currents are stronger than the cohesive forces of ice and the pack is in constant motion. After melting begins, the same pack motions create polynyas within the ice which become centers of decay as the water is warmed by the sun. A simple rule of thumb is that the ice moves 25-30 degrees to the right of the wind at about 2% of its average speed. This is the wind drag component, and the ocean current speed, if known, should be added to it.

407. OTHER ICE ENCOUNTERED AT SEA

a. *River Ice.* There is appreciable difference in the strength of fresh-water ice and sea ice, and consequently, in or near the estuaries of major rivers, an additional hazard to shipping may be encountered in spring when this river ice is carried into the sea.

b. *Ice Islands.* These are masses of ice which have broken away from the Ellesmere Ice Shelf and have an undulating surface. They have a thickness of 180 ft. (50-60 m.) with areas up to 12 sq. miles (400 sq. km.). In the final stages of melting they usually break up into a large group of tabular icebergs.

c. *Icebergs.* These are large masses of freshwater ice which have broken away from a glacier. The main source in the northern hemisphere is the Greenland ice cap, and icebergs are most common in Baffin Bay and Davis Strait although many are carried into the Grand Banks area by wind and current. (Figure 4-III.) Icebergs may reach over 300 ft. (100 m.) in height and 1600 ft. (500 m.) in length in exceptional circumstances. Their draft is usually only 2-3 times their height because of their irregular shape.

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409. ICE GLOSSARY

Aged Ridge. Ridge which has undergone considerable weathering. These ridges are best described as undulations.

Anchor Ice. Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation.

Bare Ice. Ice without snow cover.

Belt. A large feature of pack ice arrangement; longer than it is wide; from 1 km. to more than 100 km. in width.

Bergy Bit. A large piece of floating glacier ice, generally showing less than 5 m. above sea level but more than 1 m. and normally about 100–300 sq. m. in area.

Beset. Situation of a vessel surrounded by ice and unable to move.

Big Floe. (see Floe).

Bight. An extensive crescent-shaped indentation in the ice edge, formed either by wind or current.

Brash Ice. Accumulations of floating ice made up of fragments not more than 2 m. across, the wreckage of other forms of ice.

Bummock. From the point of view of the submariner, a downward projection from the underside of the ice canopy; the counterpart of a hummock.

Calving. The breaking away of a mass of ice from an ice wall, ice front, or iceberg.

Close Pack Ice. Pack ice in which the concentration is 6/8 to less than 7/8 (7/10 thru 8/10), composed of floes mostly in contact.

Compacted Ice Edge. Close, clear-cut ice edge compacted by wind or current, usually on the windward side of an area of pack ice.

Compacting. Pieces of floating ice are said to be compacting when they are subjected to a converging motion, which increases ice concentration and/or produces stresses which may result in ice deformation.

Compact Pack Ice. Pack ice in which the concentration is 8/8 (10/10) and no water is visible.

Concentration. The ratio in eighths or tenths of the sea surface actually covered by ice to the total area of sea surface, both ice covered and ice free, at a specific location or over a defined area.

Concentration Boundary. A line approximating the transition between two areas of pack ice with distinctly different concentrations.

Consolidated Pack Ice. Pack ice in which the concentration is 8/8 (10/10) and the floes are frozen together.

Consolidated Ridge. A ridge in which the base has frozen together.

Crack. Any fracture which has not parted.

Dark Nilas. Nilas which is under 5 cm. in thickness and is very dark in color.

Deformed Ice. A general term for ice which has been squeezed together and forced upwards in places (and downwards). Subdivisions are rafted ice, ridged ice, and hummocked ice.

Difficult Area. A general qualitative expression to indicate, in a relative manner, that the severity of ice conditions prevailing in an area are such that navigation in it is difficult.

Diffuse Ice Edge. Poorly defined ice edge limiting an area of dispersed ice; usually on the leeward side of an area of pack ice.

Diverging. Ice fields or floes in an area are subject to diverging or dispersive motion, thus reducing ice concentration and/or relieving stresses in the ice.

Dried Ice. Sea ice from the surface of which melt water has disappeared after the formation of cracks and thaw holes. During the period of drying, the surface whitens.

Easy Area. A general qualitative expression to indicate, in a relative manner, that ice conditions prevailing in an area are such that navigation in it is not difficult.

Fast Ice. Sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea level. Fast ice may be formed *in situ* from sea water or by freezing of pack ice of any age to the shore, and it may extend a few meters or several hundred kilometers from the coast. Fast ice more than one year old may be prefixed with the appropriate age category, old, second-year, or multi-year. If it is thicker than about 2 m. above sea level it is called an ice shelf.

Fast Ice Boundary. The demarcation at any given time between fast ice and pack ice or between areas of pack ice of different concentrations (cf. ice edge).

Fast Ice Edge. The demarcation at any given time between fast ice and open water.

Finger Rafted Ice. Type of rafted ice in which floes thrust "fingers" alternately over and under the other.

Finger Rafting. Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers" alternatively over and under the other. Common in nilas and gray ice.

Firn. Old snow which has recrystallized into a dense material. Unlike snow, the particles are to some extent joined together; but, unlike ice, the air spaces in it still connect with each other.

First-year Ice. Sea ice of not more than one winter's growth, developing from young ice; thickness from 30 cm.–2 m. May be subdivided into thin first-year ice/white ice, medium first-year ice, and thick first-year ice.

Flaw. A narrow separation zone between pack ice and fast ice where the pieces of ice are in chaotic state, that forms when pack ice shears under the effect of a strong wind or current along the fast ice boundary (cf. shearing).

Flaw Lead. A passageway between pack ice and fast ice which is navigable by surface vessels.

Flaw Polynya. A polynya between pack ice and fast ice.

Floating Ice. Any form of ice floating in water. The principal kinds of floating ice are lake ice, river ice, sea ice, which form by the freezing of water at the surface, and glacier ice (ice of land origin) formed on land or in an ice shelf. The concept includes ice that is stranded or grounded.

Floe. Any relatively flat piece of sea ice 20 m. or more across. Floes are subdivided according to horizontal extent as follows:

Giant	– Over 10 km. across
Vast	– 2–10 km. across.
Big	– 500–2,000 m. across.
Medium	– 100–500 m. across.
Small	– 20–100 m. across

Floeberg. A massive piece of sea ice composed of a hummock, or a group of hummocks, frozen together and separated from any ice surroundings. It may float up to 5 m. above sea level.

Flooded Ice. Sea ice which has been flooded by melt water or river water and is heavily loaded by water and wet snow.

Fracture. Any break or rupture through very close pack ice, compact pack ice, consolidated pack ice, fast ice, or a single floe resulting from deformation processes. Fractures may contain brash ice and/or be covered with nilas and/or young ice. Length may vary from a few meters to many kilometers.

Fracture Zone. An area which has a great number of fractures.

Fracturing. Pressure process whereby ice is permanently deformed, and rupture occurs. Most commonly used to describe breaking across very close pack ice, compact ice, and consolidated ice.

Frazil Ice: Fine spicules or plates of ice suspended in water.

Friendly Ice: From the point of view of the submariner, an ice canopy containing many large skylights or other features which permit a submarine to surface. There must be more than ten such features per 30 nautical miles (56 km.) along the submariner's track.

Frost Smoke. Fog-like clouds due to contact of cold air with relatively warm water, which can appear over openings in the ice or leeward of the ice edge and may persist while ice is forming.

Giant Floe. (See Floe.)

Glacier. A mass of snow and ice continually moving from higher to lower ground or, if afloat, continually spreading. The principal forms of glaciers are: inland ice sheets, ice shelves, ice streams, ice caps, ice piedmonts, cirque glaciers, and various types of mountain (valley) glaciers.

Glacier Berg. An irregularly shaped iceberg.

Glacier Ice. Ice in or originating from a glacier, whether on land or floating on the sea as icebergs, bergy bits, or growlers.

Glacier Tongue. Seaward projecting extension of a glacier, usually afloat. In the Antarctic, glacier tongues may extend over many tens of kilometers.

Grease Ice. A later stage of freezing than frazil ice when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matte appearance.

Gray Ice. Young ice 10–15 cm. thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure.

Gray-White Ice. Young ice 15–30 cm. thick. Under pressure more likely to ridge than to raft.

Grounded Hummock. Hummocked grounded ice formation. There are single grounded hummocks and lines (or chains) of grounded hummocks.

Grounded Ice. Floating ice aground in shoal water (cf. stranded ice).

Growler. Smaller piece of ice than a bergy bit or floeberg, often transparent but appearing green or almost black in color, extending less than 1 m. above the sea surface and normally occupying an area of about 20 sq. m.

Hostile Ice. From the point of view of the submariner, an ice canopy containing no large skylights or other features which permit a submarine to surface.

Hummock. A hillock of broken ice which has been forced upward by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a bummock.

Hummocked Ice. Sea ice piled haphazardly one piece over another to form an uneven surface. When weathered it has the appearance of smooth hillocks.

Hummocking. The pressure process by which sea ice is forced into hummocks. When the floes rotate in the process it is termed screwing.

Iceberg. A massive piece of ice of greatly varying shape, more than 5 m. above sea level, which has broken away from a glacier, and which may be afloat or aground. Icebergs may be described as tabular, dome-shaped, sloping, pinnacled, weathered, or glacier bergs.

Iceberg Tongue. A major accumulation of icebergs projecting from the coast, held in place by grounding, and joined together by fast ice.

Ice Blink. A whitish glare on low clouds above an accumulation of distant ice.

Icebound. A harbor, inlet, etc., is said to be icebound when navigation by ships is prevented by ice, except possibly with the assistance of an icebreaker.

Ice Boundary. The demarcation at any given time between fast ice and pack ice or between areas of pack ice of different concentrations (cf. ice edge).

Ice Breccia. Ice pieces of different age frozen together.

Ice Cake. Any relatively flat piece of sea ice less than 20 m. across.

Ice Canopy. Pack ice from the point of view of the submariner.

Ice Cover. The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic locale; this locale may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea.

Ice Edge. The demarcation at any given time between the open sea and sea ice of any kind, whether fast or drifting. It may be termed compacted or diffuse (cf. ice boundary).

Ice Field. Area of pack ice consisting of any size of floes, which is greater than 10 km. across (cf. ice patch).

Icefoot. A narrow fringe of ice attached to the coast, unmoved by tides, and remaining after the fast ice has moved away.

Ice Free. No sea ice present. There may be some ice of land origin (cf. open water).

Ice Front. The vertical cliff forming the seaward face of an ice shelf or other floating glacier varying in height from 2–50 m. or more above sea level (cf. ice wall).

Ice Island. A large piece of floating ice extending about 5 m. above sea level which has broken away from an Arctic ice shelf, having a thickness of 30–50 m. and an area of a few thousand square meters to 500 or more square km., usually characterized by a regularly undulating surface which gives it a ribbed appearance from the air.

Ice Jam. An accumulation of broken river ice or sea ice caught in a narrow channel.

Ice Keel. From the point of view of the submariner, a downward-projecting ridge on the underside of the ice canopy; the counterpart of a ridge. Ice keels may extend as much as 50 m. below sea level.

Ice Limit. Climatological term referring to the extreme minimum or extreme maximum extent of the ice edge in any given month or period based on observations over a number of years. Term should be preceded by "minimum" or "maximum" (cf. mean ice edge).

Ice Massif. A concentration of sea ice covering hundreds of square kilometers found in the same region every summer.

Ice of Land Origin. Ice formed on land or in an ice shelf and floating in water. The concept includes ice that is stranded or grounded.

Ice Patch. An area of pack ice less than 10 km. across.

Iceport. An embayment in an ice front, often of a temporary nature, where ships can moor alongside and unload directly onto the ice shelf.

Ice Rind. A brittle shiny crust of ice formed on a quiet surface by direct freezing or from grease ice, usually in water of low salinity. Thickness to about 5 cm. Easily broken by wind or swell, commonly breaking into rectangular pieces.

Ice Shelf. A floating ice sheet of considerable thickness showing 2–50 m. or more above sea level and attached to the coast. Usually of great horizontal extent and with a level or gently undulating surface. Nourished by annual snow accumulation and often also by the seaward extension of land glaciers. Limited areas may be aground. The seaward edge is termed an ice front (q.v.).

Ice Stream. Part of an inland ice sheet in which the ice flows more rapidly and not necessarily in the same direction as the surrounding ice. The margins are sometimes clearly marked by a change in direction of the surface slope but may be indistinct.

Ice Under Pressure. Ice in which deformation processes are actively occurring, hence a potential impediment or danger to shipping.

Ice Wall. An ice cliff forming the seaward margin of a glacier which is not afloat. An ice wall is aground, the rock basement being at or below sea level (cf. ice front).

Lake Ice. Ice formed on a lake, regardless of observed location.

Large Fracture. More than 500 m. wide.

Large Ice Field. An ice field over 20 km. across.

Lead. Any fracture or passageway through sea ice which is navigable by surface vessels.

Level Ice. Sea ice which is unaffected by deformation.

Light Nilas. Nilas which is more than 5 cm. in thickness and rather lighter in color than dark nilas.

Mean Ice Edge. Average position of the ice edge in any given month or period based on observations over a number of years. Other terms which may be used are "mean maximum ice edge" and "mean minimum ice edge" (cf. ice limit).

Medium First-year Ice. First-year ice 70–120 cm. thick.

Medium Floe. (See Floe.)

Medium Fracture. 200 to 500 m. wide.

Medium Ice Field. An ice field 15–20 km. across.

Multi-year Ice. Old ice up to 3 m. or more thick which has survived at least two summers' melt. Hummocks smoother than in second-year ice, and the ice is almost salt-free. Color, where bare, is usually blue. Melt pattern consists of large interconnecting irregular puddles and a well-developed drainage system.

New Ice. A general term for recently formed ice which includes frazil ice, grease ice, slush, and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

New Ridge. Ridge newly formed with sharp peaks; slope of sides usually 40°. Fragments are visible from the air at low altitude.

Nilas. A thin elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers" (finger rafting). Has a matte surface and is up to 10 cm. in thickness. May be subdivided into dark nilas and light nilas.

Nip. Ice is said to nip when it forcibly presses against a ship. A vessel so caught, though undamaged, is said to have been nipped.

Old Ice. Sea ice which has survived at least one summer's melt. Most topographic features are smoother than on first-year ice. May be subdivided into second-year ice and multi-year ice.

Open Pack Ice. Pack ice in which the ice concentration is 3/8 to less than 6/8 (4/10 thru 6/10) with many leads and polynyas, and the floes are generally not in contact with one another.

Open Water. A large area of freely navigable water in which sea ice is present in concentrations less than 1/8 (1/10). When there is no sea ice present the area should be termed ice free, even though icebergs are present.

Pack Ice. Term used in a wide sense to include any area of sea ice, other than fast ice, no matter what form it takes or how it is disposed.

Pancake Ice. Predominantly circular pieces of ice from 30 cm.–3 m. in diameter, and up to about 10 cm. in thickness, with raised rims due to the pieces striking against one another. It may be formed on a slight swell from grease ice, shuga, or slush or as a result of the breaking of ice rind, nilas, or, under severe conditions of swell or waves, of gray ice. It also sometimes forms at some depth, at an interface between water bodies of different physical characteristics, from where it floats to the surface; its appearance may rapidly cover wide areas of water.

Polynya. Any nonlinear-shaped opening enclosed in ice. Polynyas may contain brash ice and/or be covered with new ice, nilas, or young ice; submariners refer to these as skylights. Sometimes the polynya is limited on one side by the coast and is called a shore polynya, or by fast ice and is called a flaw polynya. If it recurs in the same position every year, it is called a recurring polynya.

Puddle. An accumulation of melt water on ice, mainly due to melting snow but in the more advanced stages also to the melting of ice. Initial stage consists of patches of melted snow.

Rafted Ice. Type of deformed ice formed by one piece of ice overriding another (cf. finger rafting).

Rafting. Pressure processes whereby one piece of ice overrides another. Most common in new and young ice (cf. finger rafting).

Ram. An underwater ice projection from an ice wall, ice front, iceberg, or floe. Its formation is usually due to more intensive melting and erosion of the unsubmerged part.

Recurring Polynya. A polynya which recurs in the same position every year.

Ridge. A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge forced downwards by pressure is termed an ice keel.

Ridged Ice. Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice (cf. ridging).

Ridged Ice Zone. An area in which much ridged ice with similar characteristics, has formed.

Ridging. The pressure process by which sea ice is forced into ridges.

River Ice. Ice formed on a river, regardless of observed location.

Rotten Ice. Sea ice which has become honeycombed and which is in an advanced state of disintegration.

Sastrugi. Sharp, irregular ridges formed on a snow surface by wind erosion and deposition. On mobile floating ice the ridges are parallel to the direction of the prevailing wind at the time they were formed.

Sea Ice. Any form of ice originating from the freezing of sea water.

Second-year Ice. Old ice which has survived only one summer's melt. Because it is thicker and less dense than first-year ice, it stands higher out of the water. In contrast to multi-year ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue.

Shearing. An area of pack ice is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to a flaw (q.v.).

Shore Lead. A lead between pack ice and the shore or between pack ice and an ice front.

Shore Polynya. A polynya between pack ice and the coast or between pack ice and an ice front.

Shuga. An accumulation of spongy white ice lumps, a few centimeters across; formed from grease ice or slush and sometimes from anchor ice rising to the surface.

Skylight. From the point of view of the submariner, thin places in the ice canopy, usually less than 1 m. thick and appearing from below as relatively light translucent patches in dark surroundings. The undersurface of a skylight is normally flat. Skylights are called large if big enough for a submarine to attempt to surface through them (120 m.) or small if not.

Slush. Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.

Small Floe. (See Floe.)

Small Fracture. 50 to 200 m. wide.

Small Ice Cake. An ice cake less than 2 m. across.

Small Ice Field. An ice field 10–15 km. across.

Snow-covered Ice. Ice covered with snow.

Snowdrift. An accumulation of wind-blown snow deposited in the lee of obstructions or heaped by wind eddies. A crescent-shaped snowdrift with ends pointing downwind is known as a "snow barchan".

Standing Floe. A separate floe standing vertically or inclined and enclosed by rather smooth ice.

Stranded Ice. Ice which has been floating and has been deposited on the shore by retreating high water.

Strip. Long narrow area of pack ice, about 1 km. or less in width, usually composed of small fragments detached from the main mass of ice, and run together under the influence of wind, swell, or current.

Tabular Berg. A flat-topped iceberg. Most tabular bergs form by calving from an ice shelf and show horizontal banding (cf. ice island).

Thaw Holes. Vertical holes in sea ice formed when surface puddles melt through to the underlying water.

Thick First-year Ice. First-year ice over 120 cm. thick.

Thin First-year Ice/White Ice. First-year ice 30–70 cm. thick.

Tide Crack. Crack at the line of junction between an immovable ice foot or ice wall and fast ice, the latter subject to rise and fall of the tide.

Tongue. A projection of the ice edge up to several kilometers in length caused by wind or current.

Vast Floe. (See Floe).

Very Close Pack Ice. Pack ice in which the concentration is 7/8 to less than 8/8 (9/10 to less than 10/10).

Very Open Pack Ice. Pack ice in which the concentration is 1/8 to less than 3/8 (1/10 thru 3/10) and water preponderates over ice.

Very Small Fracture. 0 to 50 m. wide.

Very Weathered Ridge. Ridge with very rounded tops; slope of sides usually 20° to 30°.

Water Sky. Dark streaks on the underside of low clouds indicating the presence of water features in the vicinity of sea ice.

Weathered Ridge. Ridge with slightly rounded peaks; slope of sides usually 30° to 40°. Individual fragments are not discernible.

Weathering. Processes of ablation and accumulation which gradually eliminate irregularities in an ice surface.

White Ice. See Thin First-year Ice.

Young Coastal Ice. The initial stage of fast ice formation consisting of nilas or young ice, its width varying from a few meters to 100–200 m. from the shoreline.

Young Ice. Ice in the transition stage between nilas and first-year ice, 10–30 cm. in thickness. May be subdivided into gray ice and gray-white ice.

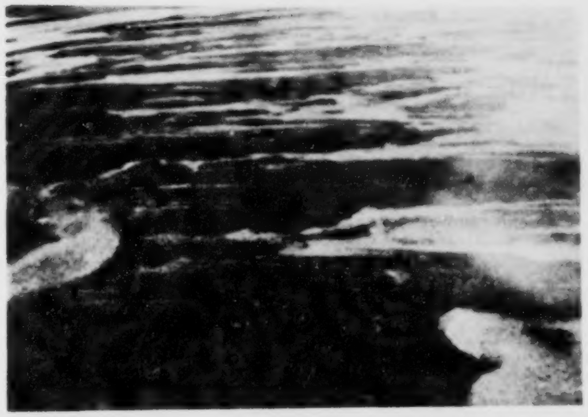


Figure 4-IV. Spongy White Ice Lumps which Retain their Characteristic Shape only when Immersed ("Shuga")

In this example a fresh wind was blowing from left to right in the picture, and the temperature was -5 to -10°C.

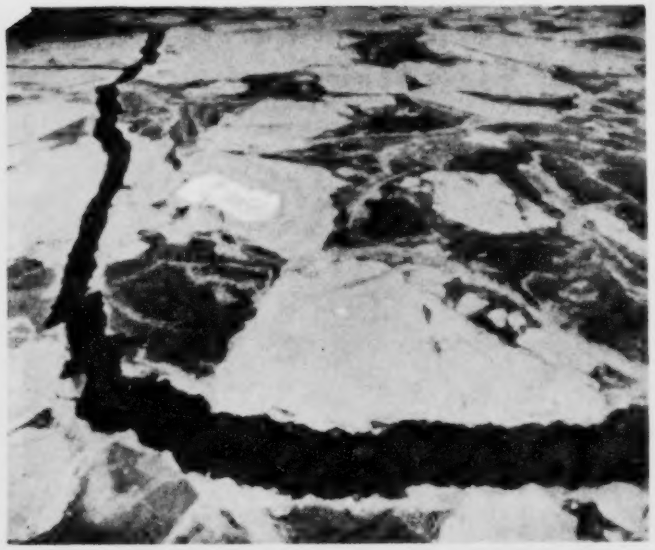


Figure 4-V. Nilas forming in a Lead through Rafted Grey and Grey-White Ice

The lead in the foreground is partially covered with dark nilas. The grey portions beyond the lead are 10-15 cm. (4-6 in.) thick, while the lighter grey-white ice is 15-30 cm. (6 to 12 in.) thick. Rafting of the floes is evident in the left foreground, in the middle foreground, and in several other areas in the middle distance.

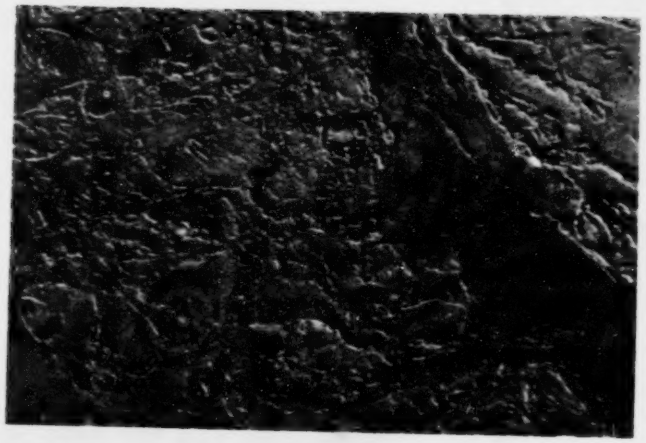


Figure 4-VI. First Year Ice with Ridges and Hummocks

Smooth areas of grey ice on the left and grey-white ice on the right, with first year ice in the center and upper right. The relief on the ice is a mixture of unorganized hummocks and clearly defined ridges, with the best example of ridging in the upper right.

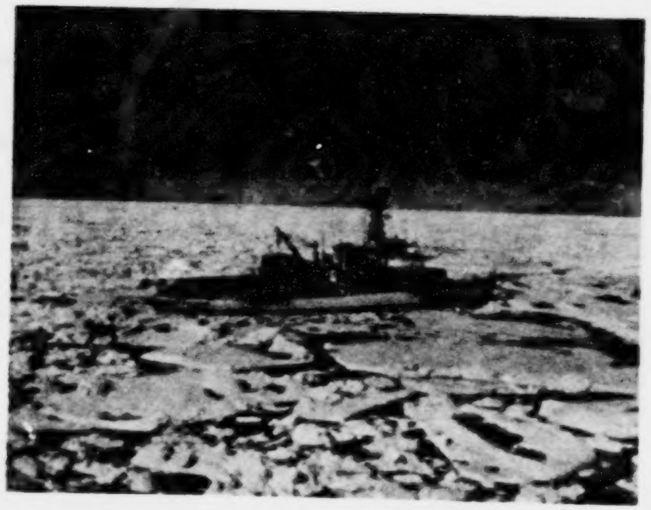


Figure 4-VII. Close Pack Ice Composed of Ice Cakes and Small and Medium Floes of Thick First Year Ice

A few puddles are evident. Only ice-reinforced ships normally venture safely into ice of this amount and type.

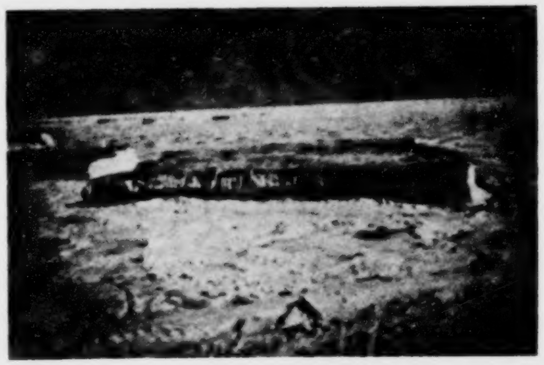


Figure 4-VIII. Ice Island Fragments in Second Year Ice

The fragments (which are aground) protrude about 20 m. (65 ft.) above the sea ice, which is still partially snow-covered even though a few puddles are evident.

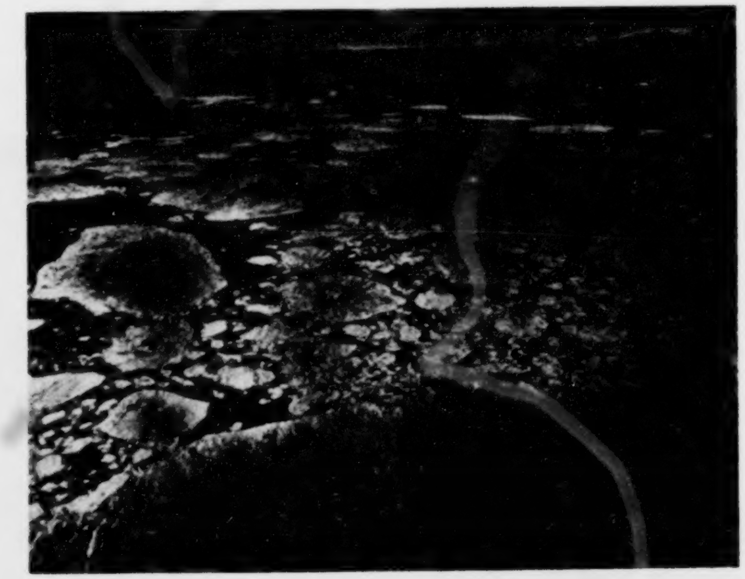


Figure 4-IX. Old Ice (Multi-Year) in Varying Floe Sizes

The drainage pattern and the subdued topography on the vast floe in the foreground indicates it is in the multi-year stage of development. The ice in the foreground and right middle ground is close pack concentration (7-9 tenths) whereas the left middle ground is open pack (4-6 tenths) and the inlet in the center background has very open pack (1-3 tenths). The two floes in the left middle ground are about 1000 m. (3,300 ft.) across and would be classed as "big". There are many medium and small floes present.

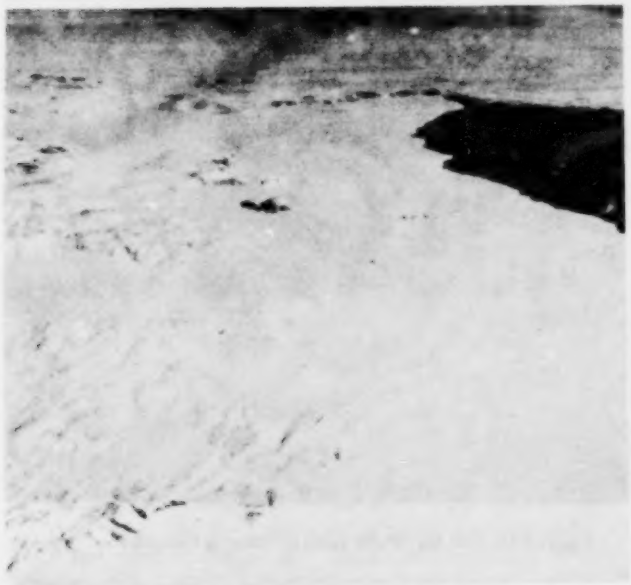


Figure 4-X. Flaw Polynya Outside Fast Ice

Smooth fast ice along the snow-covered coast with a polynya beyond it in which nilas is forming. Pack ice is also evident in the right background.

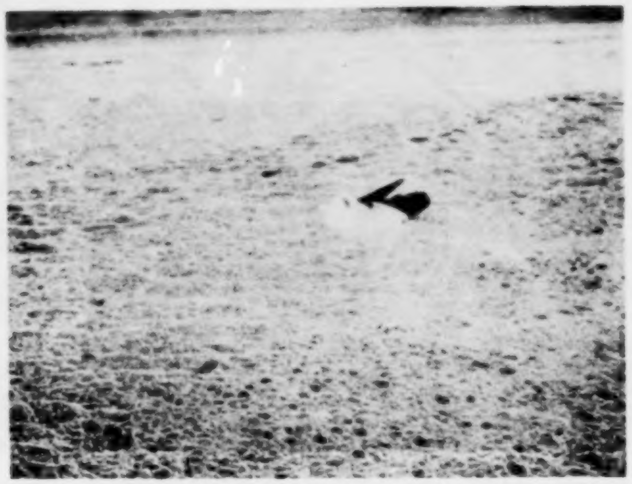


Figure 4-XI. An Iceberg in Compact Pack Ice

The pack ice surrounding this iceberg is being pressed together by wind or current and some crushing at the edges of the floe is evident. The ice is in the grey-white stage. If it were to freeze together in this position it would become consolidated pack.

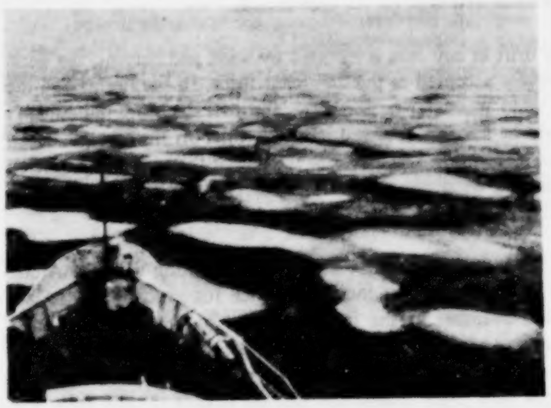


Figure 4-XII. Rotten Ice - A Smooth Even Ice Cover that has Very Nearly Melted

Many of the puddles have melted through to the sea below, becoming thaw holes, and it is difficult to tell where one floe ends and another begins. The ice is quite grayish except for the dried areas projecting very slightly above the water level.

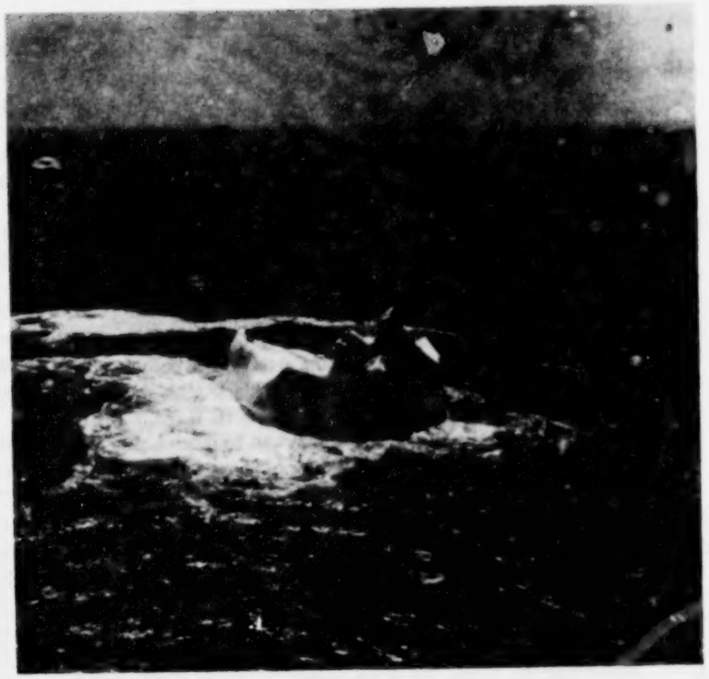


Figure 4-XIII. Iceberg and Growlers

The large growler is in the foam around the iceberg. The same thing can also occur with isolated growlers in strong winds.

SECTION II – REGIONAL ICE CONDITIONS

410. INTRODUCTION

a. The regional ice conditions of the Arctic Ocean and peripheral seas are presented in this Section. These conditions vary from year to year depending upon the climatological and oceanographic regimes. The regional information and ice coverage diagrams contained in this Section have therefore been compiled from a rough average of conditions shown on ice charts and from observations over a number of years.

b. Ice thicknesses, where given, are for first year ice undisturbed by deformation processes. Old ice in the same areas will be considerably thicker, generally 6 – 13 feet (1.8 – 4 m.) thicker. Ridges are much thicker again and such ridges are normally up to 10 ft. (3.0 m.) in height, except in the Arctic Ocean, where they can be much higher and with a ratio of height to depth below the water of about 1 to 5.

c. For specific operational and planning purposes, it is essential that the appropriate Sailing Directions, charts, ice atlases and ice reconnaissance reports be consulted.

411. BERING SEA AND SEA OF OKHOTSK

a. About half the Bering Sea is ice-covered in winter, the ice being almost entirely of local formation and therefore of one winter's growth only. Old ice from the Arctic Ocean does enter in the autumn on the west side of Bering Strait, but usually in small quantities and not every year. It seldom penetrates farther south than Bukhta Provideniya (Provideniya Bay). Shore-fast ice begins to form in the bays of the northwest coast of the Bering Sea in early October. On the east side it is perhaps a little later, but the first ice has formed in the Norton Sound area by mid or late October. Pack ice follows the same pattern, appearing in the Gulf of Anadyr' in October and in Norton Sound in November. It builds outwards from the coasts and southward from Bering Strait, reaching a maximum in February or March, and retreating northward again through April and May. On the Alaska side the last pack ice disappears in June, but off the Siberian coast it is sometimes found well into July. Fast ice, which is the last to go, may also linger into July, especially on the Siberian side. Figures 4-XIV and 4-XV show the approximate extent of ice for each month.

b. Ice drift in any area is dictated by wind and current, the wind being generally accepted as the dominant force. In the Bering Sea the prevailing wind in winter is northerly, and it is therefore natural that there should be a strong observed southerly drift off the Siberian coast, where wind and current coincide. For the rest of the area drift direction is more variable, wind and current forces often being in opposition, but the general net drift is south.

c. The Sea of Okhotsk has no direct connection with the Arctic Ocean, so here all ice is of local origin. Ice formation starts in late October or November in the northwest part of the sea and spreads southeastward. As in the Bering Sea, deterioration of the ice cover starts in April in the south, and the ice has usually all gone by the end of June, though some may linger around the Shantar Islands till mid July. The prevailing drift is towards the Kuril Islands and is strongest along the coast of Sakhalin, where the prevailing northerly winds coincide with the south-flowing East Sakhalin Current. From January to March there is ice in the straits between the more southerly of the Kuril Islands, and this ice sometimes moves out into the Pacific before melting.

d. Navigation in both the Bering and Okhotsk Seas in winter is possible with existing icebreakers. United States "Wind" Class icebreakers have carried out many winter operations in the Bering Sea, but little or no other shipping enters the ice-covered parts of the sea in winter. The frequent winter storms can cause heavy pressure, and north of St. Lawrence Island in particular, the ice is subject to this pressure, which can create navigational difficulties. In the Sea of Okhotsk the port of Nagaevo (Magadan) is in operation all winter, using ice-strengthened vessels with icebreaker escort. It would not be practical to use unstrengthened ships in either sea in winter. Maximum ice thickness in both seas (not counting thicknesses due to ridge formation or rafting of floes) is in the order of 3 ft. (1 m.).

412. CHUKCHI SEA

a. Ice in the Chukchi Sea, as in the other seas that open directly on to the central Arctic Ocean, consists of two types: locally formed first-year ice and heavy old polar ice. The first category forms in the fall or during the winter, and in summer either melts or drifts north to add to the polar pack ice. The second category drifts south from the polar pack and may be present in varying quantities at any time of year. Particularly in summer, when the local ice has mostly dissipated, the polar pack may drift south under the influence of northerly winds and create problems for shipping. This is especially true at the northern points of the Sea, such as Point Barrow. Generally, however, conditions are fairly open in summer, particularly in the southern half of the sea, largely owing to the warm current that flows north through Bering Strait.

b. Ice begins to form in late September in the northern coastal areas, and in sheltered inlets such as Kotzebue Sound by mid or late October. On open coasts fast ice may not form for another month. Pack ice, made up of varying proportions of locally formed ice and old ice from the polar pack, spreads southward, filling the entire sea by early November. Fast ice extends about 30 miles (48 km.) offshore in the western part of the Sea; elsewhere the fast ice strip is much narrower except in deep bays.

c. Break-up begins in late June or early July and proceeds from south to north. Its speed and extent probably depend mainly on the volume of the Bering Strait current. This current spreads out in three tongues, west through Proliv Longa (DeLong Strait), northwest towards Ostrov Geral'd (Herald Island) and northeast along the Alaskan coast. The open water follows the current, leaving two ice massifs (persistent large areas of pack ice) between the tongues. The Russians call these the Wrangel and North Chukchi Massifs respectively. A third, the Kolyuchin Massif, is found off the Siberian coast west of Mys (Cape) Serdtse-Kamen'. The Wrangel and Kolyuchin Massifs usually disappear by the end of August, but the North Chukchi Massif, which is the only one to contain large quantities of old ice, may persist till freeze-up in bad years. In good years the sea may be open right up to about 73°N.

d. Navigation is possible in the Chukchi Sea in all summers, but only strengthened ships can be sure of any degree of freedom of operation, and icebreaker escort is often necessary. Difficult points are the massifs mentioned above, and especially the area of Point Barrow, where in bad years the heavy ice is close to shore all season and pressure is often considerable. Dates of passing Point Barrow are mid to late July in most years, and the end of September is about the deadline for outbound passage at the end of the season. The open season along the Siberian coast is rather longer, roughly from mid June to the end of September. Icebreakers have penetrated into the polar pack ice in this area on several occasions. In 1967 the "Wind" Class Icebreaker *U.S.C.G.C. Northwind* reached 78°43'N, 167°W, where she suffered damage to her screws. *U.S.C.G.C. Staten Island* and the Canadian Icebreaker *C.C.G.S. John A. Macdonald* joined her there on October 3 and successfully escorted her out of the ice.

413. BEAUFORT SEA

a. The Beaufort Sea is open to, and is really a part of, the Arctic Ocean, and therefore the full weight of the permanent polar pack ice is frequently felt in this area. In summer the polar pack may stay close to shore or retreat anywhere up to 200 miles from the coast, depending on the wind and temperature patterns in any given year. Consequently, in winter, the ice in this wide belt may be predominantly multi-year ice or almost entirely first-year ice, according to conditions at the time of freeze-up. Generally, the polar pack comes closest to the coast at the

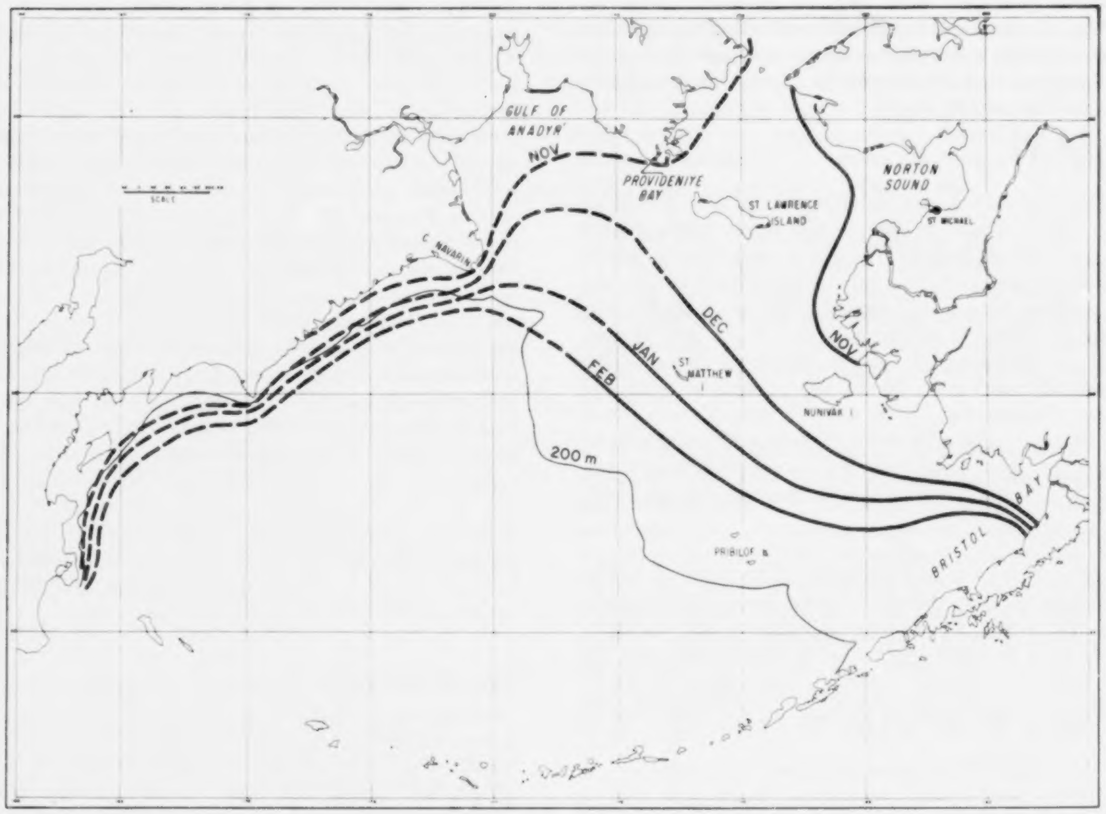

GULF OF ANADYR'
NOV
PROVIDENIYE BAY
ST LAWRENCE ISLAND
NORTON SOUND
ST MICHAEL
SCALE
C NAVARIN
DEC
JAN
ST MATTHEW I
NUNIVAK I
NOV
FEB
200 m
PRIBILOF Is
BRISTOL BAY

Figure 4 - XIV. Bering Sea: Approximate Monthly Limits of Pack Ice for November-February

Based on mean values of USN reconnaissance data (solid lines) and typical limits for the same months from Russian sources (dashed lines).

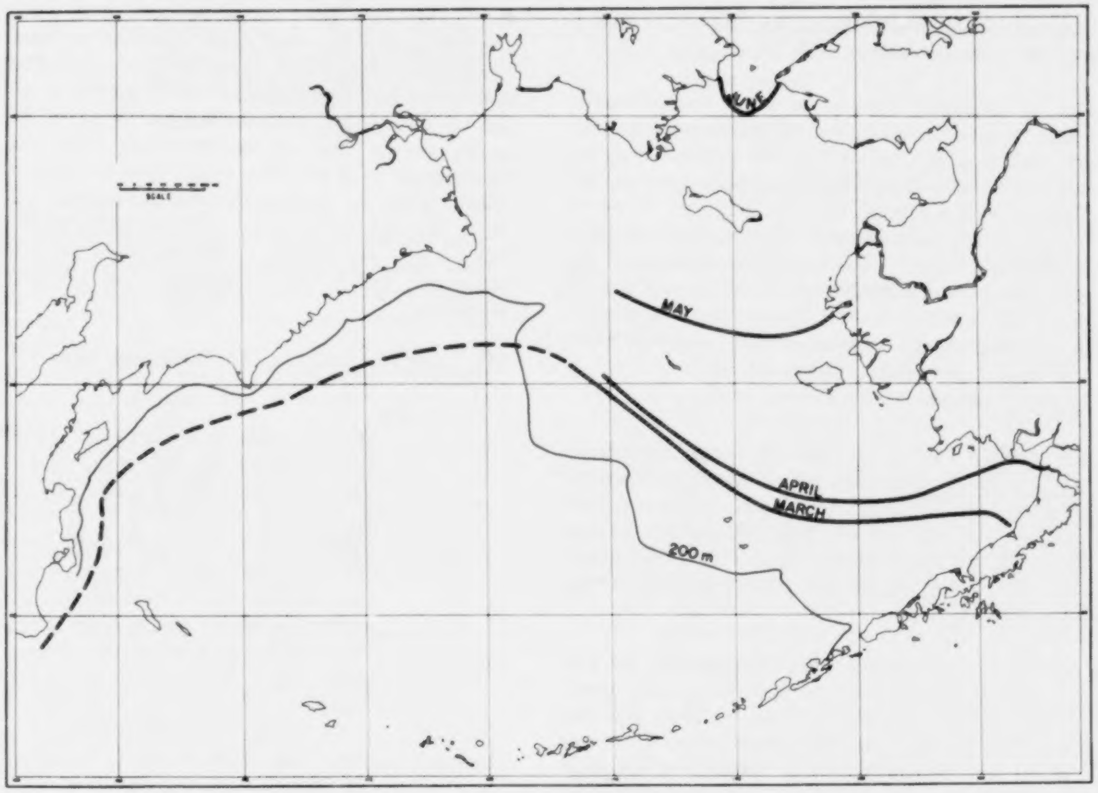

JUNE
MAY
APRIL
MARCH
200 m
SCALE

Figure 4-XV. Bering Sea: Approximate Monthly Limits of Pack Ice for March-June

Based on mean values of USN reconnaissance data (solid lines) and typical limits for the same months from Russian sources (dashed lines).

points of the coastal arc that border the sea, i.e., from Point Barrow eastwards and off the northwest coast of Banks Island.

b. Minimum ice conditions occur in the second half of August, when the first-year "in-shore" ice has melted and when open water may extend 100-200 miles from the coast if the polar pack is well to the north. In a bad year however there will be little open water and the pack ice will have a high proportion of multi-year floes. Freeze-up begins in late September or early October and the area of Amundsen Gulf is usually the last to freeze. From Cape Bathurst westwards the coastal area is shallow and a considerable breadth of fast ice forms. By late December the first-year ice is 30–40 inches (0.7 – 1.2 m.) thick in the Mackenzie Bay area, and 40–48 inches (1.0 – 1.4 m.) off Banks Island. By late April it has reached around 60 inches (1.6 m.) in Mackenzie Bay and 75 inches (1.9 m.) elsewhere.

c. In April southeast winds become prevalent in the Cape Bathurst area, and a polynya usually forms between the fast ice of Amundsen Gulf and the drifting pack ice, which tends to move offshore with the wind. The influence of this polynya gradually spreads, reaching Mackenzie Bay in July and Barter Island by mid-month. By mid-August a lead will usually form joining this area to the open Pacific round Point Barrow and through Bering Strait.

d. The movement of the Beaufort Sea ice varies with the wind patterns, but is strongly influenced by the polar pack, which is in a state of continual, if slow, motion as part of a clockwise gyre that characterizes the North American side of the Arctic Ocean. This motion is controlled by the pressure systems over the Arctic Basin as a whole, and does not depend very greatly on the local wind conditions in the Beaufort Sea area, where the trend is usually off-shore in summer and on-shore in fall and early winter. Because of the pressures exerted by the motions of the polar pack, ridging and lead formation are major considerations, and very extreme pressures are often engendered off all coasts facing on the Arctic Ocean.

e. Ships have sailed the Bering Strait route into Alaska and the Canadian Arctic for many years, including an intensive period of whaling and trading activity in the late 19th and early 20th centuries. It is at times a difficult route because of the movements of the polar pack, and the present fairly extensive resupply to the Arctic coast is largely carried out by way of the Mackenzie River, trans-shipping at Tuktoyaktuk to ships which winter there. However, stations on the Alaskan coast are supplied by icebreaker-escorted convoys from the Bering Sea, and the Canadian small icebreaker *C.C.G.S. Camsell* (4,250 SHP) makes the passage in and out every year, though she has occasionally had to call for assistance from a larger ("Wind" Class) icebreaker.

414. LAPTEV AND EASTERN SIBERIAN SEAS

a. *General*

(1) The ice conditions of the Laptev and the East Siberian Seas are more severe than in any other of the peripheral seas off northern Asia. Sea ice forms unusually quickly as the water temperatures of the shallow seas drop rapidly in the autumn. Hummocky ice more than 30 ft. (10 m.) high is common at the boundary of the fast ice and pack ice, and is most strongly developed in the western Laptev Sea and in Proliv Longa. In the spring the ice melts first at the mouths of rivers and along the nearby coasts. The rivers freeze between October and December, and their flow throughout the winter either ceases or is low. Ice is up to 8 ft. (2.5 m.) thick on the large rivers. Break-up is at the end of May or the beginning of June. On large rivers this involves violent ice movement, ice dams and flooding. The ice on the smaller rivers melts in place. The navigation period for the lower reaches of the rivers is 3-4 months.

(2) In summer, Proliv Dmitriya Lapteva tends to have

favourable ice conditions but P. Sannikova and P. Longa are rarely completely free of ice, and P. Vil'kitskogo has the worst ice conditions. This is caused by drift of ice with the current from the Kara Sea, and pack ice and icebergs that drift southeast from Severnaya Zemlya.

b. *Laptev Sea*

(1) Break-up begins in June off the deltas of the Lena and Yana Rivers. The eastern side of the Laptev Sea is the first to be free of ice because of the influx of river water and the presence of winds blowing the ice off-shore. Changes in the western part are slower because of the deeper water and the cold current that flows south along the east coast of Severnaya Zemlya. Once the ice has broken up in the west, the ice margin retreats 10-25 miles a day (15-40 km.). The southern part of the Laptev Sea is navigable in July, but there may not be access to it from the seas on either side. Heavy pack ice from the polar basin does not extend far into the Laptev Sea (unlike the East Siberian Sea) and only small quantities find their way south. The navigation season is effectively August and September.

(2) Freeze-up begins at Tiksi, in Guba Buorkhaya (Buorkhaya Gulf) in early October and spreads from there, east and west. By December the sea is completely frozen over. Ice conditions vary from the west to the east. In the west there is much hummocky and rafted ice because of the wind. There are often large fields of heavy sea ice off Severnaya Zemlya and Taymyr' where heavy floes and icebergs may run aground as they are driven southward. In the eastern part, the ice is generally smoother and 60-90 in. (150-225 cm.) thick. The fast ice is 10-15 miles (15-25 km.) wide off the northeastern parts of Taymyr', 50-60 miles (80-100 km.) wide along the southern shores of the sea, and 250 miles (400 km.) wide from the mainland to north of the Ostrova Novosibirskiye.

c. *East Siberian Sea*

(1) In the East Siberian Sea the first open water appears in late June off the Kolyma Delta. Open water expands rapidly west of the Kolyma and the ice edge moves to the north. In the eastern sector of the sea, the ice does not begin to clear for 1-2 weeks longer. The navigation season is 8-10 weeks in the west and 6-8 weeks in the east. During this period, ice conditions in the western sector are usually favourable for navigation. Proliv Dmitriya Lapteva is clear of ice and in the late summer it is sometimes possible to pass north of Ostrova Novosibirskiye. The Ostrova De-Longa are usually surrounded by drifting ice and bergy bits that have calved from small glaciers on the islands. In the eastern section, conditions are generally neither so good nor are they as predictable. The heavy pack of the polar basin approaches the coast more frequently here than anywhere else along the whole north Siberian shore. However, during the late summer, there is usually an open lead close to the shore up to 20 miles (32 km.) wide.

(2) Freeze-up begins in the west and by late November there may be an unbroken surface extending 180-300 miles (300-580 km.) offshore in the west, narrowing to 10-20 miles (15-30 km.) off Mys Shmidta. Ice is constantly on the move in Proliv Longa.

d. *The Islands.* Around Ostrov Vrangelya navigation is possible only during the last half of August and September. Proliv Dmitriya Lapteva is normally open for navigation from late July or early August and September. The seas surrounding the Ostrova Novosibirskiye are rarely free of pack ice; the minimum concentration occurs in September.

415. BARENTS SEA

a. The Barents Sea is exceptionally ice-free when compared with the other peripheral seas of northern U.S.S.R. This is a consequence of the warm Atlantic water entering the Sea. The inflow is sufficient to keep the southwestern sector free of sea ice all year, and causes ice conditions in the rest of the Sea to be much less severe than is normal for the latitude. Ice conditions may be predicted by measuring the flow of the North Atlantic Drift north of Scotland. Warmer water there is followed by better ice conditions in the Barents Sea two years later.

b. Negligible quantities of ice enter the Barents Sea from the Kara Sea and the Arctic Ocean, and all sea ice may be considered local. Maximum ice cover is in April, when the sea is ¾ covered. The mean southerly limit of unnavigable ice at this time runs from the southwest coast of Svalbard to Björnöya (Bear Island) and east to 73° 30′N, 40°E and the mainland at Mys Svatoy Nos. Significantly the Murman coast is always open. In the spring the ice margin recedes east and north and by mid-June it can be navigated north of Björnöya and east to 50°E. At O. Kolguyev in the southeast of the Barents Sea, ice lasts until the end of July. Ice conditions are best in September when the mean ice limit runs from southern Svalbard to Z. Frantsa Iosifa, and continues east-southeast to 40 miles (65 km.) north of Novaya Zemlya. Occasionally in late August the Barents Sea is entirely free of ice.

c. Freeze-up begins in October in the shallow waters around Z. Frantsa Iosifa, Novaya Zemlya, Svalbard and the estuary of the Pechora. During November the west coast of Novaya Zemlya freezes, and by December most of the sea north of 75°N is frozen. The ice margin moves gradually south and west as the winter progresses. Winds and currents have a strong effect on the ice conditions, because there is much open water in the west. Between February and April, if southeast winds are unusually strong, the ice will be driven to the northeast, leaving much open water in the southwestern quadrant of the sea.

d. Ice conditions in the White Sea vary radically from year to year as a result of the strength and direction of prevailing winds. In October landfast ice begins to spread from gulfs and bights. By January the sea is frozen over, but ice is very thin in the central part and the entrance to the sea is still ice-free. Maximum ice is in February and March and by then ice is thickest in the entrance, which is still blocked in May. Grounded hummocks form a chain north of O. Morzhovets. Break-up begins in late April and by June the sea is ice-free again. The ice is usually forced out into the Barents Sea to melt, and in consequence Mys Kanin Nos is often surrounded by floating ice until the end of June.

e. Z. Frantsa Iosifa is rarely clear of ice. The south part of the archipelago may be ice-free for a few weeks, but the narrower straits are ice-bound all year. Western Novaya Zemlya is clear of ice from the end of July until October. In January there is much loose pack ice to the west of the island. From February to April Novaya Zemlya and Z. Frantsa Iosifa are completely surrounded by land-fast ice, break-up beginning in May. Small icebergs may be found in the vicinity of both island groups, since both have glaciers which reach the sea.

416. KARA SEA

a. There is floating ice all year in the Kara Sea, the amount and distribution depending largely on the strength and direction of the prevailing winds. Most of the ice originates in the Kara Sea itself, as currents and shallow water in the north act as barriers to the heavier pack ice of the Polar Basin. Break-up advances from the south, where it is essentially open by July. Optimum navigation conditions are in August and September, but in good years last from July to October. The worst conditions for navigation are usually encountered near P-ov.

Taymyr' where ice collects in the narrow straits separating the islands of Arkhipelag Nordenshel'da and blocks the area immediately west of P. Vil'kitskogo. Conditions are very variable elsewhere in the Kara Sea: but ice is apt to be heavy either in the northwest or the southwest. Small icebergs may be met off northern Novaya Zemlya and Severnaya Zemlya.

b. Mainland rivers begin to freeze in October at the river mouths and at the same time fast ice develops around their mouths. Fast ice forms quickly and, anchored by the many islands, remains all winter. Along eastern Novaya Zemlya fast ice is 3 – 5 miles (5-8 km.) wide and north of the mainland it may exceed 15 miles (20 km.). The pack in the central Kara Sea is 6 – 10 ft. (2-3 m.) thick, or considerably thicker where ridged or hummocked by pressure. "Stamukhi" (grounded hummocks) are common off Novaya Zemlya and Severnaya Zemlya. They reach heights of 30 ft. (10 m.) and tend to retain the surrounding ice cover in position.

c. Ice conditions around Severnaya Zemlya are variable. The navigation season is usually from mid-August to mid-September. East of the archipelago there is ice all year, including some icebergs. East winds drive much of this ice into the straits between the islands and make them impassable.

417. APPROACHES TO THE LINCOLN SEA (NARES STRAIT)

a. The ice in Nares Strait is virtually shorefast in winter from Robeson Channel to Smith Sound, but owing to shoreline configuration and wind and current patterns, open leads are often found across the northern entrance to Robeson Channel and in Kennedy Channel. At the head of Smith Sound, the fast ice of Kane Basin ends in an extremely stable northward-curving line from Ellesmere Island at about Pim Island to the Greenland coast. South of this is the "North Water", remaining more or less open all winter and extending southward through Smith Sound. This feature, not yet fully understood, is probably a flaw lead caused by a combination of northerly winds blowing off the fast ice of Kane Basin and the south-flowing current and net southerly drift of the ice in Baffin Bay.

b. Ice formation starts early in September, at which time there may already be large quantities of ice in the area, as it is never completely ice-free. Coverage is pretty well complete in October, but movement continues for some time and it is not known exactly when the ice bridge at Smith Sound forms. Thickness records are missing for this area, but a maximum of 90 inches (2.3 m.) is to be expected, occurring in May or June.

c. Surface melting starts in June, but the North Water ice bridge does not usually break up until late July or even August, when a general break-up occurs in Kane Basin and the ice of the whole channel starts to move south, some melting *in situ*, some in the warmer water of Baffin Bay. The ice remaining varies in concentration and position, though there is a tendency for the narrow channels to be clearer than the basins, where the ice often collects. In some years Nares Strait becomes fairly clear, in others concentrations of up to 7/8 remain all season. The proportion of old ice is high.

d. A number of exploring vessels, strengthened, but by modern standards greatly under-powered, reached the shores of the Lincoln Sea through this channel between 1870 and 1910. More recently the US Coast Guard supplied Alert by sea for several years by "Wind" Class icebreaker, but this was given up because of difficulty of access. However the problem was mainly in the Lincoln Sea sector, and passage within Nares Strait by icebreaker is usually not too difficult in the summer season.

418. BAFFIN BAY AND DAVIS STRAIT

a. Owing to the presence of a warm northerly current off the Greenland coast and a cold southerly current off Baffin Island, there is considerable contrast between ice conditions on the east and west sides of Baffin Bay and Davis Strait. The east side remains clear in winter, except for fast ice in the fiords, almost as far north as Disko Bay, while the west side is completely ice-covered. In summer the ice clears out completely or almost completely, the remaining ice, if any, being on the west side of Baffin Bay. The ice is therefore mostly of one year's growth, though, apart from the little that may remain from one year to the next, intrusions from Nares Strait bring some older ice to the west side of the bay.

b. Ice formation starts in the north in late September and advances southwards to Davis Strait by mid October. The whole area to the limits of ice formation is covered with pack ice by early November (See Figure 4-XVI.) Thicknesses by late December have reached about 30 inches (0.7 m.) in northern Baffin Bay and 15 – 20 inches (0.4 – 0.5 m.) in the Disko – Cape Dyer area; and maximum growth, which is reached around the end of April, is about 60 inches (1.5 m.) in northern Baffin Bay and 50 inches (1.3 m.) in Davis Strait. Fast ice extends offshore for varying distances, the widest extent being in Home Bay, where the fast-ice edge follows a line from Cape Henry Kater to Broughton Island.

c. The pack ice in this area moves back and forth with the wind and also to the south on the west side of the Bay in a net drift of about 5 miles a day. As a result of these various forces, ridge formation and leads occur throughout the season. In particular, owing probably to the southerly net ice drift and prevailing northerly winds, an open patch is almost always present north of Baffin Bay in Smith Sound, and the southern limit of this patch is associated with varying concentrations of young and generally weak ice. This area is known as the "North Water".

d. In May the North Water spreads southward towards Melville Bay and the entrance to Lancaster Sound, and open water begins to creep up the Greenland coast from the south towards Melville Bay (See Figure 4-XVII.) By early June general melting has started. An open water route is usually available through Melville Bay by late July. The last ice usually persists off the east coast of Baffin Island in the area of Home Bay. In some years ice remains here all summer, but more usually all ice has gone by September.

e. Navigation in virtually open water is available in the area from late July to October. (See Figure 4-XVIII.) Icebreaker operations are probably possible all year at least up the Greenland coast, but this has not so far been attempted between November and May. "Wind" Class ships, however, have been to Thule in November and May and have crossed Baffin Bay from Egedesminde to Cape Christian in the latter month.

f. Baffin Bay is the major source area of the icebergs that drift down to the Grand Banks, and they are found here in tremendous numbers. The greatest concentrations are in the source areas of Disko Bay and Melville Bay. From here and other points on the Greenland coast they drift north on the West Greenland Current, crossing the bay at various points and then drifting south with the Canadian Current. They may thus be found in any part of the bay, but tend to be more plentiful in the major current flow areas off the east and west coasts. A photographic count conducted by the US Coast Guard in 1949 totalled 40,232 bergs. South of Disko Bay very few are found on the Greenland side. (See Figure 4-XIX.)

419. NORTHERN CANADIAN ARCTIC ARCHIPELAGO (QUEEN ELIZABETH ISLANDS)

a. The northwest part of the Queen Elizabeth Islands contains the most severe ice conditions in the entire Arctic outside of the central Arctic Ocean. The area bounded by the north coasts of Prince Patrick, Melville and Bathurst Islands, the south coast of Amund Ringes Island and the southwest corner of Axel Heiberg Island never becomes clear and hardly ever even breaks up. Only in a very few open seasons do open water tongues erode the edges of this ice area (see ice coverage diagram, Figure 4-XX.) For most of the year the entire area of the

Queen Elizabeth Islands is enclosed by fast ice, with a very high concentration and proportion of old ice in the sector outlined above, and with varying proportions in the rest of the area, depending on the previous summer's conditions. The amount of ridging also varies, partly with the amount of old ice present, but more significantly with the occurrence or absence of storms during the freeze-up process.

b. Freeze-up starts early in September in the northwest or in areas where much ice has remained over the summer season, and rather later elsewhere. Among the later areas is Eureka Sound, where a surprisingly continental type of climate exists, characterized by warm summers, bringing relatively early break-up and late freeze-up, and cold winters. Eureka weather station at 80°N has consistently thicker ice than Alert, on the shores of the Arctic Ocean. Freeze-up starts in mid or late September, and at about the same date in Penny Strait, Wellington Channel and Jones Sound. Thicknesses of first-year ice in early November are around 2¼ ft. (0.7 m.) in most areas, with average maximum thickness, reached in May or June, of 7¼ ft. (2.2 m.).

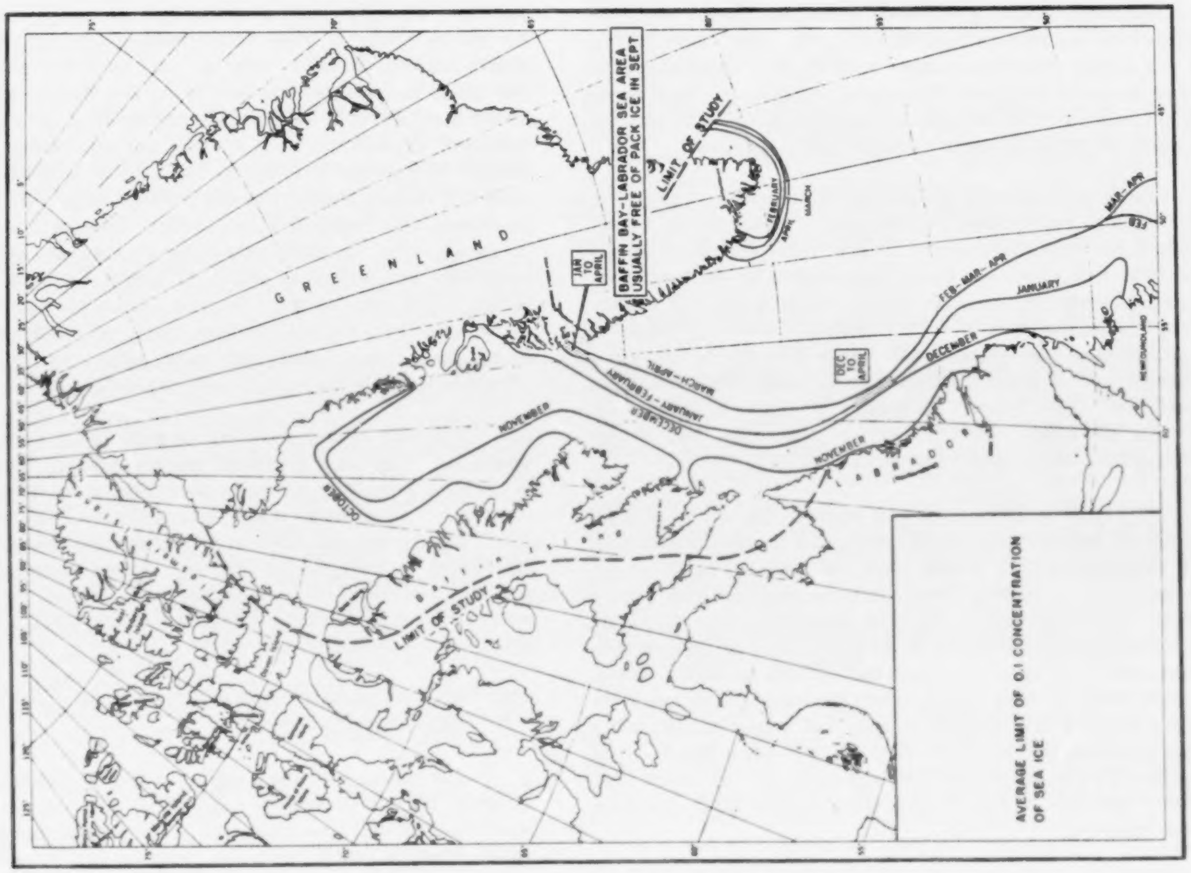
c. The dates at which movement ceases in the various channels have not yet been recorded. In the northwest it is probably quite soon after freeze-up starts, if indeed there has been any movement in summer, which is relatively rarely. In areas that have been open it probably varies from year to year, but general fast ice conditions are likely to exist by mid December at the latest. There are however areas of open water in winter. One of these that has been mentioned already, the North Water of Smith Sound, affects the fringes of this area at the entrance to Jones Sound, where an open lead is characteristic, with a tongue extending into Jones Sound south of Cobourg Island. At the other end of Jones Sound, Hell Gate and Cardigan Strait remain open all winter, probably because of the speed of the currents through these narrow channels.

d. Break-up starts in Jones Sound with the spreading of both the above-mentioned polynyas, and with the development of patches in the fast ice in Queens Channel in May. By the end of June, Queens Channel and Penny Strait have broken up into pack ice, and by mid July only the middle section of Jones Sound remains icebound. At this time Eureka Sound is starting to break up, the process normally starting at Stor Island and moving north and south, and, by mid August, Jones Sound is usually clear and Eureka Sound nearly so. At the same time Wellington Channel breaks up, allowing any ice remaining in Queens Channel to move out into Barrow Strait, where it usually melts. The remaining waters outside the line mentioned in para a are less predictable. Norwegian Bay and Belcher Channel seldom become completely clear. In the north, Nansen Sound also seldom clears completely and sometimes not at all. Greely Fiord and the fiords leading off it may or may not clear. Byam Martin Channel and Fitzwilliam Strait also vary between open and completely blocked. Penny Strait, which opens very early, often becomes completely choked in August by ice breaking up to the north of it.

e. The only regularly travelled sea route in the Queen Elizabeth Islands is through Jones Sound and Norwegian Bay to Eureka, and this is navigated every year by one or more icebreakers. Since 1962 this route has been extended north through Greely Fiord to Tanquary Fiord, but the ship has failed to get through this area twice (out of eight trips). In 1969, for the first time, a strengthened freighter was successfully escorted to Eureka. On one occasion the icebreaker returned by way of Belcher Channel and Penny Strait, but the Jones Sound route is considered more reliable.

420. SOUTHERN CANADIAN ARCTIC ARCHIPELAGO (INCLUDING PARRY CHANNEL)

a. The channels of the Canadian Arctic Archipelago, generally speaking, become increasingly icebound as one proceeds north and west. Thus the least open conditions are experienced in the northwest Queen Elizabeth Islands, while the waters south of Parry Channel are mostly relatively open in summer. In this southern sector the least favourable conditions are to be found in M'Clure Strait, Viscount Melville Sound, and M'Clintock Channel. The last named in particular


GREENLAND
JAN TO APRIL
BAFFIN BAY-LABRADOR SEA AREA USUALLY FREE OF PACK ICE IN SEPT
LIMIT OF STUDY
FEBRUARY
MARCH
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MAR-APR
FEB
FEB-MAR-APR
JANUARY
DEC TO APRIL
DECEMBER
MARCH-APRIL
JANUARY-FEBRUARY
DECEMBER
NOVEMBER
OCTOBER
NOVEMBER
LABRADOR
NEWFOUNDLAND
BAFFIN ISLAND
LIMIT OF STUDY
AVERAGE LIMIT OF 0.1 CONCENTRATION OF SEA ICE

Figure 4 - XVI. Freeze-up Season, Baffin Bay-Labrador Sea Area

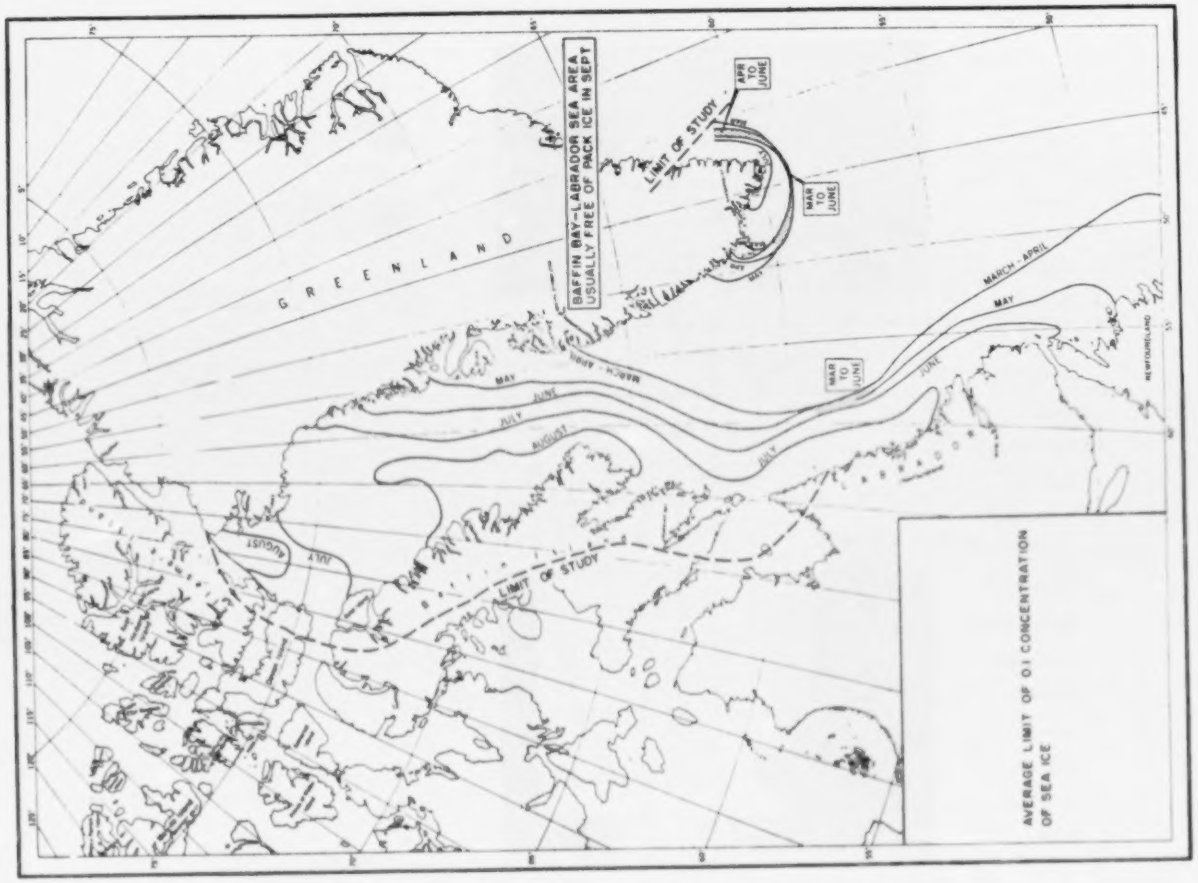

GREENLAND
BAFFIN BAY-LABRADOR SEA AREA
USUALLY FREE OF PACK ICE IN SEPT
LIMIT OF STUDY
APR TO JUNE
MAR TO JUNE
MAR TO JUNE
MARCH - APRIL
MAY
JUNE
JULY
AUGUST
MARCH - APRIL
MAY
JUNE
JULY
AUGUST
JULY
AUGUST
LABRADOR
LIMIT OF STUDY
NEWFOUNDLAND
AVERAGE LIMIT OF 0.1 CONCENTRATION OF SEA ICE

Figure 4 - XVII. Break-up Season, Baffin Bay-Labrador Sea Area

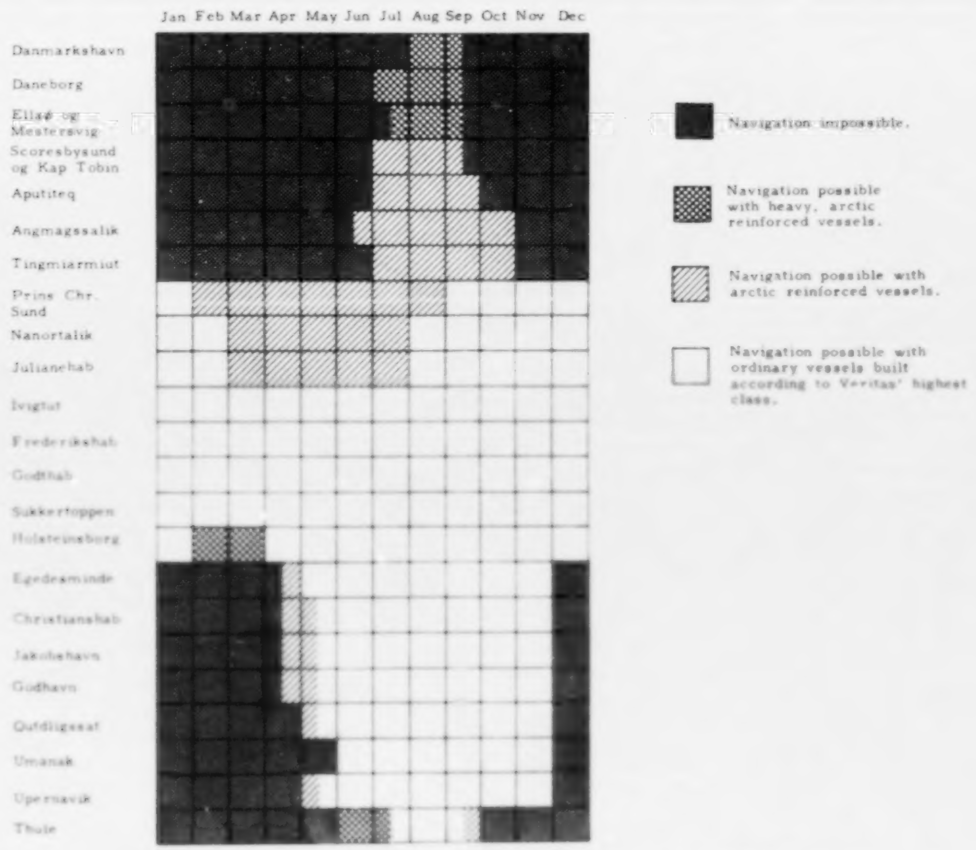
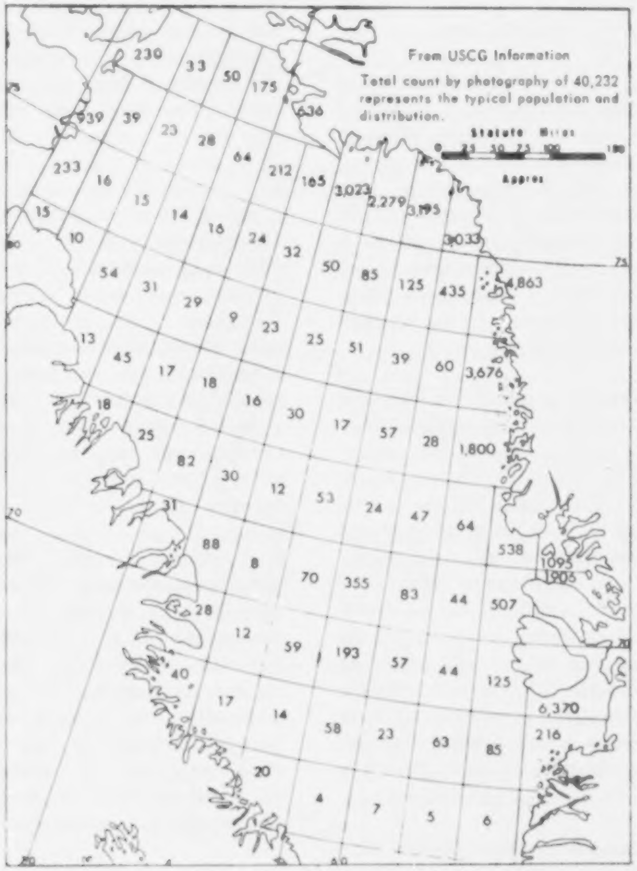


Figure 4 - XVIII. Navigation Conditions, East and West Coasts of Greenland



From USCG Information

Total count by photography of 40,232 represents the typical population and distribution.

Statute Miles
0 25 50 75 100 150
Approx
75
75
70
70
80
60
230
33
50
175
636
939
39
23
28
64
212
165
3,023
2,279
3,195
233
16
15
14
16
24
32
3,033
15
10
50
85
125
435
4,863
54
31
29
9
23
25
51
39
60
3,676
13
45
17
18
16
30
17
57
28
1,800
18
25
82
30
12
53
24
47
64
31
88
8
70
355
83
44
538
1095
1905
28
12
59
193
57
44
507
40
17
14
58
23
63
125
6,370
216
85
20
4
7
5
6

Figure 4 - XIX. Baffin Bay Iceberg Census, August 1949

very seldom opens up, due to lack of currents or to some local climatic factor that is not yet understood.

b. In all the channels, except Lancaster Sound and the north part of Prince Regent Inlet, the ice is fast from shore to shore in winter and spring and there is virtually no movement. The proportion of old to first-year ice varies according to the conditions of the previous summer – the more ice there is remaining over the summer, the more second-year ice there will be the following season. A very open summer is not always, however, followed by another open season, as it sometimes enables heavy ice to drift in from other areas before freeze-up. Also, an optimum year in one area is often a poor one in some other area, so that the very open conditions shown on the chart (Figure 4-XX) are unlikely to occur all at the same time.

c. Freeze-up starts in early September in the earliest areas and early to mid October in the latest. The earliest areas are usually M'Clure Strait, Viscount Melville Sound, and M'Clintock Channel, but any area which has retained a substantial ice cover throughout the summer will tend to freeze early, as the presence of ice speeds up the cooling process. Conversely, the early areas are liable to freeze rather later in the years when they experience a more than normally open season. Next to freeze are the north-south channels of Prince of Wales Strait, Victoria Strait, and Peel Sound, and finally Lancaster Sound and Prince Regent Inlet in the east and the channels bordering the mainland in the south. These latter usually freeze from east to west, and Amundsen Gulf is often still largely open in mid October. The Gulf of Boothia, the "dead end" of Prince Regent Inlet, often retains considerable ice cover and freezes early. Thickness of first-year ice in early November is about 2 ft. (0.6 m.) in most areas, and the maximum thickness, reached in most places in May, is around 7 ft. (2.1 m.).

d. Limited movement in all the channels continues for some time after freeze-up. Data on date of cessation of movement are very scarce, but by the end of December probably all areas have become shore-fast except those that usually remain in motion all winter – Lancaster Sound, Prince Regent Inlet, and Amundsen Gulf. In Lancaster Sound a lead is often present along the north side of the strait, sometimes curving round to the west side of Prince Regent Inlet. Open patches are also common in Amundsen Gulf, often as a lead from southern Banks Island to Cape Parry. These areas form centres for the start of break-up, large areas of open water forming in May and early June.

e. Break-up proper does not usually start until July, and navigation is not at present attempted into Barrow Strait and along the north mainland coast until August, by which time, in a reasonably good year, fairly open conditions can be expected in these areas. In bad years, however, ice may be encountered in any part of the channels throughout August. In all the north-south channels there are years when conditions remain fairly congested all summer, or when open conditions do not occur until just before freeze-up. The most likely to clear is Prince Regent Inlet, where open water is the rule rather than the exception, and the least likely is M'Clintock Channel, where open conditions are very rare. The others fall between these extremes. M'Clure Strait also seldom clears, but Viscount Melville Sound often has open water on the north side.

f. All the channels in this area have been navigated at least once, and regular re-supply operations are carried out to Resolute and throughout the channel along the north mainland coast. Unstrengthened vessels with icebreaker escort make an annual voyage to Resolute, but only at the height of the season. On the mainland coast unstrengthened ships can be used, but access round Point Barrow would be problematical. The present supply vessels, which are unstrengthened, winter at Tuktoyaktuk, near the Mackenzie delta. In all other areas strengthened ships are essential. Winter navigation has not yet been attempted and would not be possible for existing icebreakers except very possibly into Lancaster Sound as far as Resolute.

421. HUDSON STRAIT AND BAY

a. Hudson Bay and Strait are completely ice-covered in winter and completely open in summer, and the ice found there is all first-year ice except for occasional older floes in the area adjacent to Foxe Channel, which sometimes present a hazard to shipping in September. At times, some older ice also drifts into the eastern part of Hudson Strait from Davis Strait.

b. Ice begins to form in late October or early November in the north of Hudson Bay around Southampton Island and the west coast north of Churchill, and the limit of ice creeps southward and eastward till the whole Bay and Strait are covered by the beginning of January. Maximum thickness of undisturbed ice is reached in early April and is about 5 ft. (1.5 m.).

c. In May the first signs of break-up appear round the shores, and by late July the ice has usually practically gone, the last ice persisting in the southwestern part of the Bay, but this will vary according to the wind patterns prevailing at the time. Some ice may be found south of the entrance to Foxe Channel throughout August, but seldom in sufficient quantity to present a problem.

d. The ice in Hudson Bay and Strait is in continual movement through the winter, but the coverage is more than 7/8. Generally there is a high incidence of ridging. The small amount of open water takes the form of leads which form to offset the ridges, and also wider and more stable flaw leads which occur between the coastal fast ice and the pack ice with offshore winds. The northwest coast of Hudson Bay is the most frequent area for such leads owing to the prevalence of northwest winds in winter, and these leads may be 10 miles or more in width at times. In Roes Welcome Sound there is often quite considerable open water. In Hudson Strait leads are more commonly found on the north side than on the south. The width of fast ice varies from a few yards to several miles and is to some extent linked with water depth, being widest where the water is shallow.

e. Hudson Bay is accessible to unstrengthened ships from late July to the end of October, sometimes longer. Harbour conditions however sometimes cut down the operating period; thus the official (insurance) season for Churchill is 21 July to 15 October, and this is a realistic limit for the port. Strengthened ships could operate over a longer period, and it is probable that icebreakers could penetrate Hudson Strait at any time of year and possibly parts of the Bay as well, but this has not yet been attempted.

422. FOXE BASIN

a. Ice in Foxe Basin is mostly but not all of one year's growth. Apart from local ice that sometimes survives the summer, there is some old ice that enters through Fury and Hecla Strait. However, even the first-year ice tends to be anomalously thick for the latitude. The normal maximum ice thickness at Hall Beach is 86 inches (2.3 m.) as compared to 78 inches (2.0 m.) for Resolute, and the pack ice has a reputation for difficulty of navigation. The reason for this is partly because it is a shallow rather cold sea and partly because a combination of high tidal ranges, strong tidal currents and stormy weather lead to a great deal of movement and ridging activity. In the extensive shallows, furthermore, ice forms on the bottom at low tide and then floats off, carrying considerable quantities of silt. The continuous repetition of this process leads to dirty brown coloured ice which is typical of much of the ice in Foxe Basin.

b. Ice begins to form in October, usually about mid-month but sometimes earlier, and by some time in December the whole area, including Foxe Channel, is covered. Fast ice covers the shallow eastern part of the Basin but is narrower on the west coast, and the pack ice in the body of the Basin is on the move throughout the winter. Open water leads are thus found off the fast-ice edge at various points according to wind direction.

c. In late April and early May the open water begins to spread in the northwest part of the Basin to produce a fairly stable polynya, which however does not usually grow at all rapidly until early or mid July. At this time true break-up may be said to start from the northwest and also from the southeast, proceeding rather slowly to produce easy passage by late August and complete or almost complete open water by mid-September.

d. Shipping into Foxe Basin was limited to one or two ships a year until the building of the DEW Line in the 1950's. Since then a considerable re-supply tonnage has been shipped in every summer by icebreaker-escorted ships. In 1955 the icebreaker *HMCS Labrador* entered Foxe Basin in early July and reached the Hall Beach area by following the western shore of the Basin. A convoy of unstrengthened ships was subsequently escorted to DEW Line sites at the head of Foxe Basin in mid August.

423. LABRADOR SEA AND NEWFOUNDLAND WATERS

a. Ice in the Labrador Sea is limited to a strip about 100-150 nautical miles wide off the coast of Labrador. It is made up partly of locally formed pack ice and partly of ice that drifts down from Davis Strait with the Labrador Current. Fast ice covers all the coastal fiords. The pack ice is of various ages, but first-year ice predominates. Concentration varies with wind direction. As winter winds are predominantly northeasterly to northerly, the concentrations tend to be fairly high.

b. Fiord ice starts to form in early or mid December and reaches its maximum thickness in April of about 30-40 inches (0.7 – 1.2 m.) in the south and 36-50 inches (1.0 – 1.4 m.) in the north. At the inland station of Goose Bay ice formation starts about three weeks earlier. The pack ice spreads southwards from Davis Strait in November and by the end of December has usually reached the Strait of Belle Isle, continuing down the coast of Newfoundland in January and February. Its maximum extent is usually reached about the middle of February off the Avalon Peninsula, though sometimes it extends well to the south of it.

c. In April and May the winds tend to become westerly, the ice is driven eastward into warmer water and melts, starting a northward retreat of the pack. It clears Belle Isle Strait about the end of May in most years and the northern Labrador coast about the third or fourth week in July.

d. Of great importance to shipping in this area are the icebergs, which occur in large numbers throughout the same area as the pack ice, but extend rather farther eastward and also southward to near 42°N. Accurate mean figures on the distribution of icebergs are not available for the Labrador coast. The bergs come down the Labrador coast from Baffin Bay and are not directly related in any way to the pack ice. They can occur at any time of year, but those making the southern half of their voyage in the winter have more chance of surviving to reach their southern limit. Thus, of those reaching the Grand Banks, 94 percent arrive between the beginning of March and the end of June, and 64 percent in April and May. In the summer and fall they tend to melt farther north.

e. Navigation in any part of this area should be possible at any time of year for heavy icebreakers, but has not as yet been practised. However, Canadian icebreakers have entered Lake Melville more than once in April. Attempts by the same vessels (*C.C.G.S. John A. Macdonald* and *C.C.G.S. d'Iberville*) to make this fast-ice passage in January and February have been unsuccessful, but passage through the pack ice of the Labrador Sea was successfully made in all cases.

424. GULF OF ST. LAWRENCE

a. The ice cover in the Gulf of St. Lawrence varies in extent from year to year, and ranges from minimum ice cover in the west and southwest parts of the Gulf only, to the other extreme of virtually complete ice cover in the Gulf which may persist for as much as four weeks. Except for a small amount of older ice which sometimes comes through the Strait of Belle Isle in the spring, all ice is of one season's growth only, and much of it never gets past the young ice stage of development. Maximum thickness is about 30 inches (0.7 m.).

b. Ice formation usually starts in the river below Quebec about mid December, and in Chaleur Bay and Northumberland Strait in the second half of the month. Maximum extent is reached about mid or late February, but growth is not always continuous up to this time. Warm temperatures can occur at any time during the growth season and temporarily reverse the trend.

c. The final retreat of the ice normally starts some time in March, and complete clearing occurs any time from late April to the end of May. Open water passage through the Gulf is nearly always possible any time after the end of March and sometimes sooner.

d. From this description it might appear that the Gulf of St. Lawrence ice would present few problems to navigation, but this is not always the case. Stormy weather causes much ridging and rafting of the ice, and pressure at times can be severe. It is by no means uncommon for even the icebreakers to be temporarily immobilized by pressure even in this relatively thin ice. Nevertheless navigation is maintained throughout the winter with icebreaker assistance. In 1968 a total of 688 vessels entered the Gulf between 15 December (1967) and 15 April, of which only 223 were ice-strengthened. Well-strengthened ships such as the Danish "Dan" ships and the Soviet "Lena" Class can reach Montreal throughout the winter and seldom require any assistance.

425. NORTHEAST ATLANTIC AND EAST AND NORTH GREENLAND

a. The northeast Atlantic has ice on its northern fringe only. As in all such ice-edge areas, the position of the ice edge is dependent on local atmospheric and ocean circulation, and is quite uneven. Thus, on the east coast of Greenland, in the shadow of a cold land mass and with a cold current flowing from the Arctic Ocean, ice extends to below 60°N in winter, whereas on the east side open water is found as far north as 75° in the Barents Sea and often to 80° off the west coast of Svalbard. This is about 840 nautical miles (1550 km.) farther north than any other open sea at this season, and is of course due to the Gulf Stream waters which penetrate into the Arctic Ocean in this area and modify the whole climate of northern Europe.

b. *East Greenland*

(1) The East Greenland Ice originates mainly in the Arctic Ocean, but is supplemented by locally formed ice. It characteristically contains a high proportion of old ice. This pack ice, together with a small number of icebergs from glaciers in northeast Greenland, is carried south by the East Greenland Current as a broad belt which is about 270 nautical miles (500 km.) wide north of Scoresby Sound (70°N) in late winter. North of this latitude there is ice at all seasons, but the belt narrows and concentrations decrease in late August. Beginning in September, the southern and southeastern margin of the pack ice expands southwards until by December or January a tongue of pack ice has reached Kap Farvel and has effectively blocked the east coast. Between January and May it continues round Kap Farvel up the west coast as far as Frederikshaab, or occasionally in very severe years as far as Godthaab. Whilst the pack ice develops offshore, the fiords begin to freeze in October and the ice remains until the following June and July; when the fiords clear of fast ice they are commonly filled with pack ice blown in by onshore winds. The maximum cover of East Greenland Ice is reached in March and April, and in very heavy ice years there is at that time continuous pack ice from southern Greenland to Svalbard and eastwards to Novaya Zemlya. The margin of the ice begins to withdraw in May by melting on the outer side and by the development of inshore leads between the coast and the open pack.

(2) In the most favourable years, the limit of pack ice in August may be as far north as 75°, whilst in a bad year ice may still reach Kap Farvel at this time. Great fluctuations have been recognized in the extent of the East Greenland Ice and this is clearly related to the rate of transport by the current and amount of ice that is offered from the Arctic Ocean. Although in general it appears to have been less in the 20th Century than in the previous three centuries, forecasting the quantity and distribution of the East Greenland Ice is still not possible.

(3) Only three glacier systems in east Greenland are significant producers of icebergs. The most active glaciers calve into Scoresby Sound and may contribute 40 percent of the total iceberg production. Iceberg calving begins in July and continues through the latter part of the summer. Few icebergs actually reach the polar pack and move south with it, as the majority become stranded in the fiords or trapped in the many offshore islands. With lesser concentrations of pack ice, more icebergs move south, as the bergs will be less apt to be blocked by the pack.

c. *Iceland and the Norwegian Sea*

(1) The seas around Iceland occasionally were reached by pack ice before the climatic improvement of the present century. In one unusual year in the nineteenth century (1888), ice appeared off the north coast in December 1887, and by June had spread clockwise round the island until only the west coast was ice-free. Similar conditions were found in 1881. In the last thousand years the island has been surrounded by ice probably several times each century, although the variations from one century to another have been considerable. Since 1920 sea ice has appeared off the north coast of Iceland on only a few occasions.

(2) Jan Mayen Island and Björnöya (Bear Island) are normally reached by pack ice and remain surrounded for two to four months, although as the ice margin is not far away during this period conditions are variable. Except for the inner fiords, no ice is found along the north Scandinavian coasts.

d. *Svalbard.* The west coast of Svalbard is free of ice or experiences only limited bad ice conditions, whilst the east and north coasts experience very heavy pack ice. Fast ice generally develops on the west coast of Vest Spitsbergen in December, but in some years a continuous ice cover fails to form in winter. This inshore ice melts in April or May; it may be replaced by pack ice later in the summer in the south, but north of Isfjorden the sea is normally ice-free. On the east coast, local fast ice, icebergs from glaciers, and pack ice that has been carried from the east, block the coast for the first half of the year. The northwest part of the western part of the north coast is generally the most accessible.

e. *North Greenland.* In Peary Land, fast ice remains in the fiords from September to the end of July and is rarely broken up by gales once it has formed. In unusually cold summers it may fail to melt and "sikussaq" (old fast ice) is formed. This ice may survive several decades and becomes fresh and re-crystallised; only with difficulty can it be differentiated from glacier ice. "Sikussaq" is found in several fiords, including J.P. Koch's Fjord and Independence Fjord. On some coasts in north Greenland the ice foot is practically permanent, but the ice breaks up in most fiords and open water is found for a short period along the coast. Throughout the year heavy pack ice is present off the coast.

426. THE POLAR BASIN

a. Sea ice in the Polar Basin grows to a thickness of 6 ft. (2 m.)

during the first year. Subsequently, it grows more slowly, reaching an equilibrium thickness of 10-13 ft. (3-4 m.) after a period of 5-8 years. The ice cover is marked by leads and pressure ridges which form as the wind and currents deform it. On the Eurasian side, the ice moves directly toward the opening between Svalbard and Greenland. This was clearly illustrated during the drift of ice station Arlis II. The swiftest part of the drift occurs off eastern Greenland where steady speeds in excess of one kt. have been logged. Ice on the Canadian side moves circularly in a clockwise gyre: the drift of Fletcher's Ice Island (T-3) provided an example of this. The ice island made two orbits of the gyre in 17 years. In the vicinity of the North Pole there is an ice divergence which separates the two patterns of drift. The exact location of the divergence varies from year to year. Even though the tracks of Arlis II (Figure 4-XXIX) and T-3 were similar on the Canadian side, Arlis II exited into the East Greenland Current but T-3 remained locked in the gyre.

b. Superimposed on these broad patterns are many irregularities of drift. The small scale motions are due to wind, and ice floes move at a rate of about one-fiftieth the speed of the wind and in a direction 30° to the right of the wind. The steady wind drift of the ice is easily detected with daily celestial fixes. There is finally a still smaller scale of ice motion with a period of about 12 hours which can only be detected with more precise and frequent fixes. The ice describes clockwise circles with a diameter of approximately one kilometre. These are inertial motions representing the transient response of the ice to changing wind conditions.

Figure 4 - XX. Light Summer Ice Conditions, Beafort Sea to Lincoln Sea (1-15 September)
(On facing page)

BEAUFORT SEA TO LINCOLN SEA

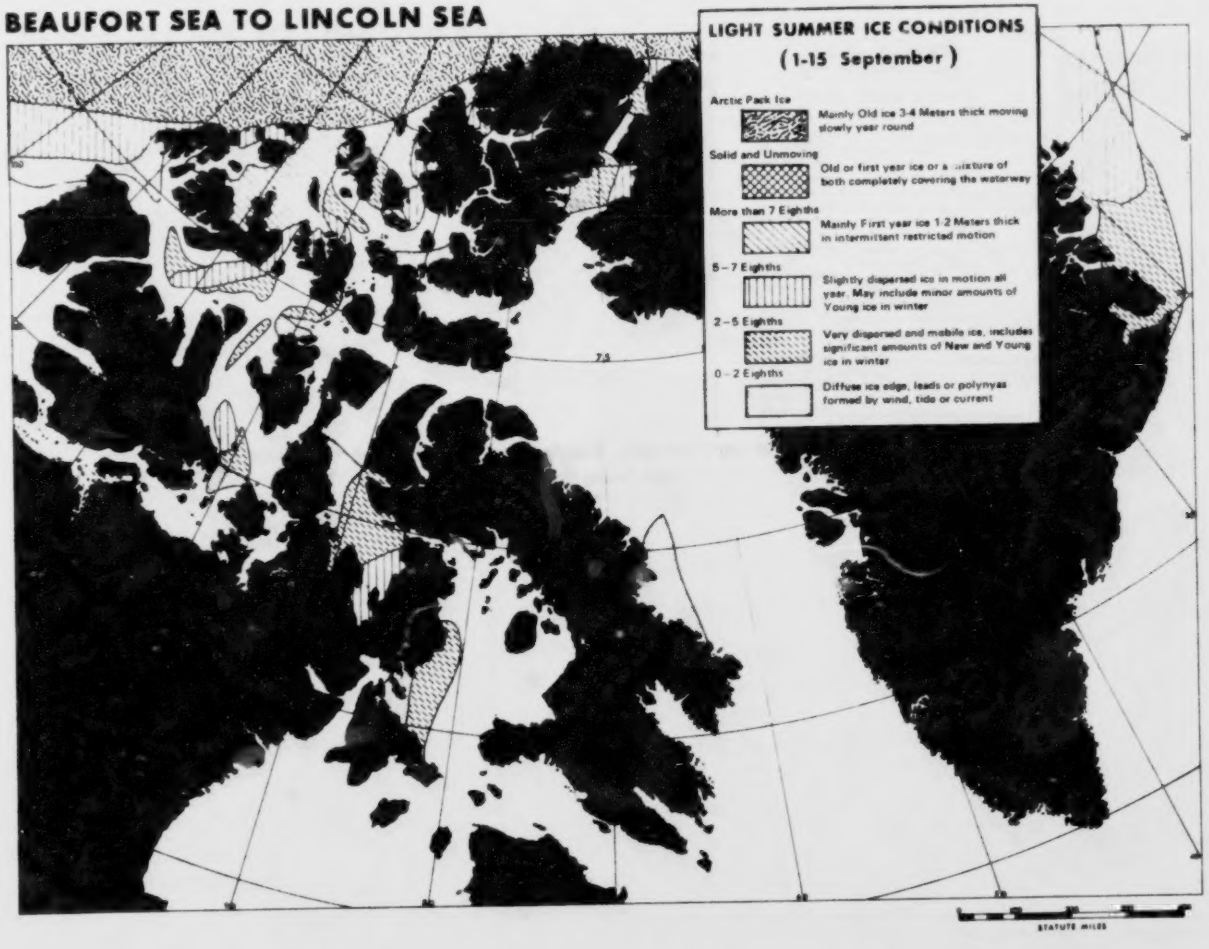
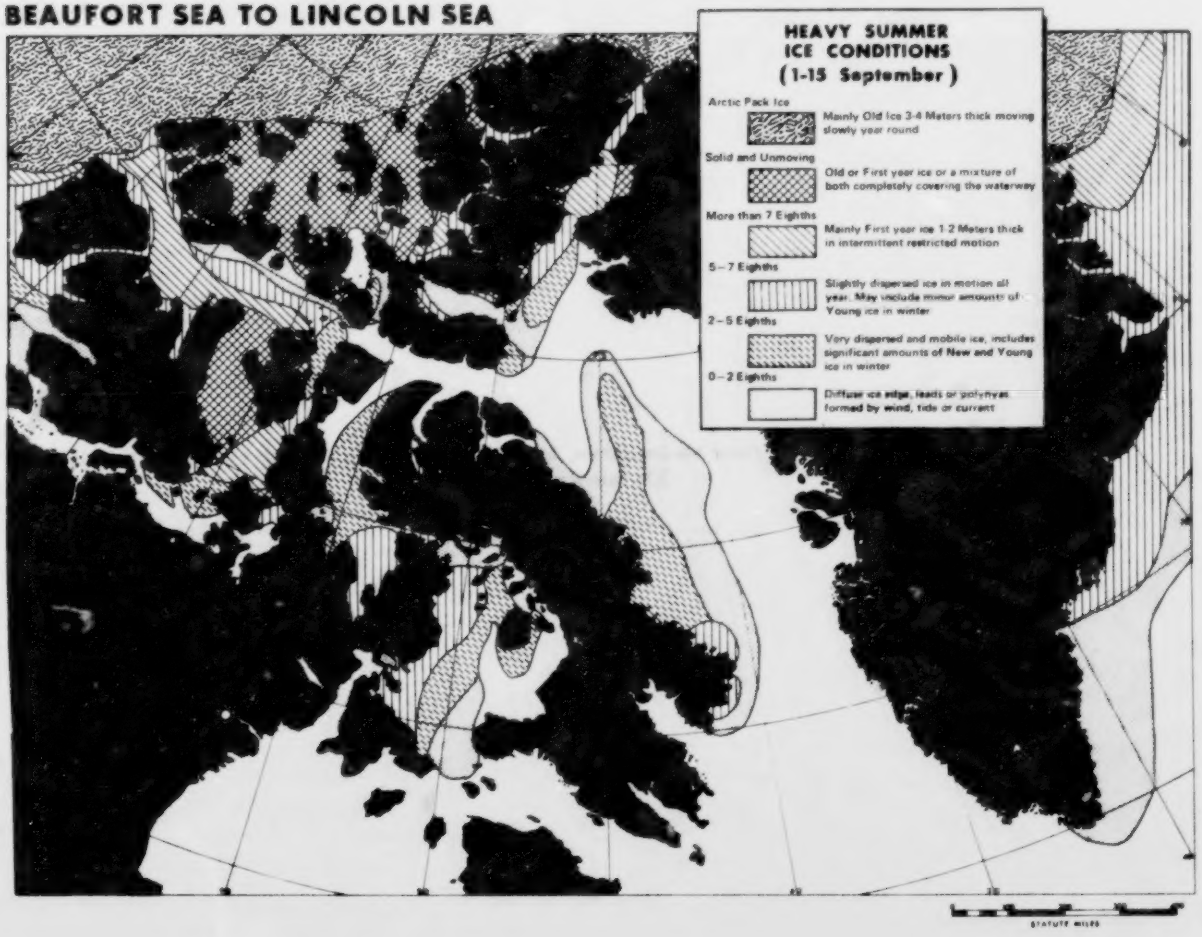

LIGHT SUMMER ICE CONDITIONS
(1-15 September)
Arctic Pack Ice
Mainly Old ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or first year ice or a mixture of both completely covering the waterway
More than 7 Eighths
Mainly First year ice 1-2 Meters thick in intermittent restricted motion
5 – 7 Eighths
Slightly dispersed ice in motion all year. May include minor amounts of Young ice in winter
2 – 5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0 – 2 Eighths
Diffuse ice edge, leads or polynyas formed by wind, tide or current
75
STATUTE MILES

Figure 4 - XXI. Heavy Summer Ice Conditions, Beaufort Sea to Lincoln Sea (1-15 September)
(On facing page)

BEAUFORT SEA TO LINCOLN SEA



HEAVY SUMMER
ICE CONDITIONS
(1-15 September)
Arctic Pack Ice
Mainly Old Ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or First year ice or a mixture of both completely covering the waterway
More than 7 Eighths
Mainly First year ice 1-2 Meters thick in intermittent restricted motion
5 – 7 Eighths
Slightly dispersed ice in motion all year. May include minor amounts of Young ice in winter
2 – 5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0 – 2 Eighths
Diffuse ice edge, leads or polynyas formed by wind, tide or current
STATUTE MILES

Figure 4 - XXII. Typical Winter Ice Conditions, Beaufort Sea to Lincoln Sea (February)
(On facing page)

BEAUFORT SEA TO LINCOLN SEA

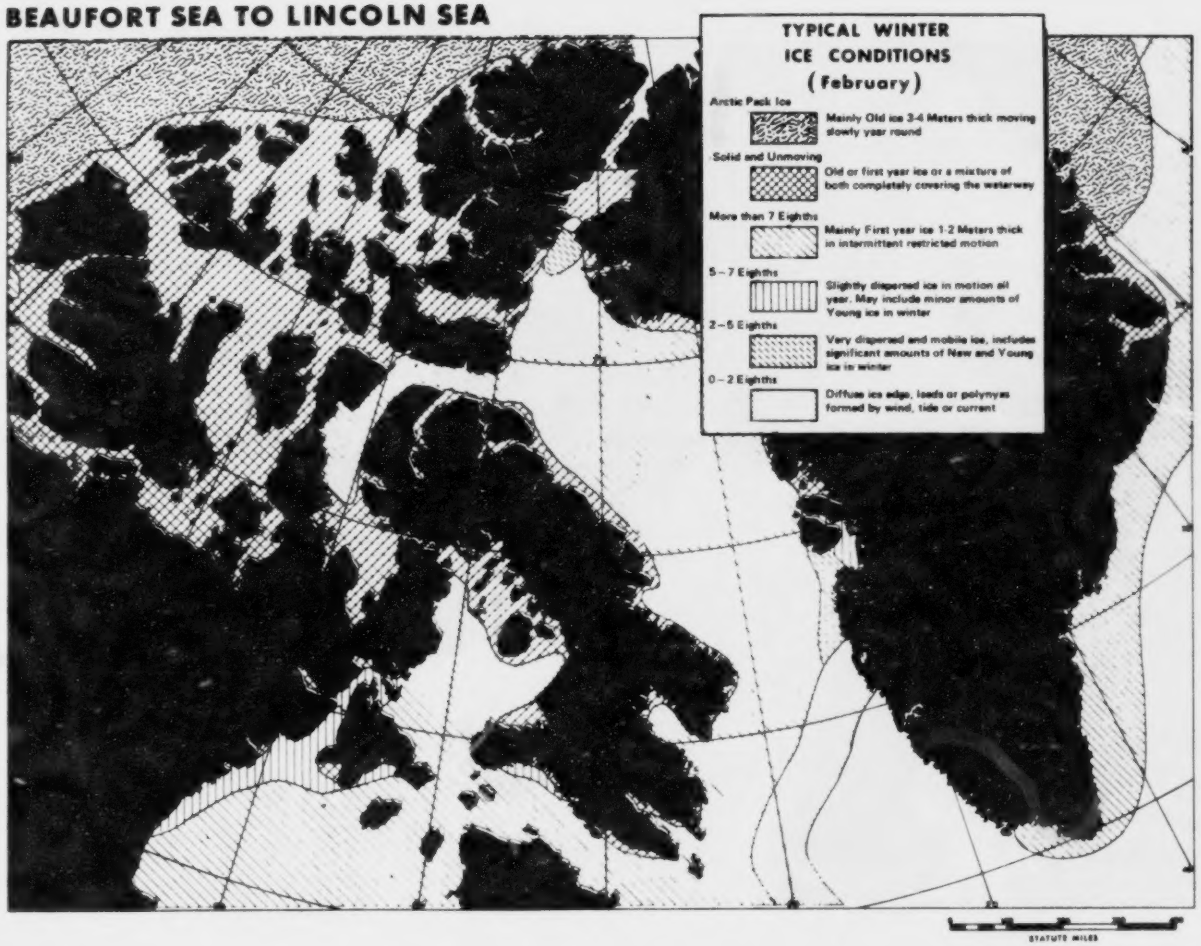

TYPICAL WINTER
ICE CONDITIONS
(February)
Arctic Pack Ice
Mainly Old ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or first year ice or a mixture of both completely covering the waterway
More than 7 Eighths
Mainly First year ice 1-2 Meters thick in intermittent restricted motion
5 – 7 Eighths
Slightly dispersed ice in motion all year. May include minor amounts of Young ice in winter
2 – 5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0 – 2 Eighths
Diffuse ice edge, leads or polynyas formed by wind, tide or current
STATUTE MILES

Figure 4 - XXIII. Light Summer Ice Conditions, Lincoln Sea to Laptev Sea (1-15 September)
(On facing page)

LINCOLN SEA TO LAPTEV SEA

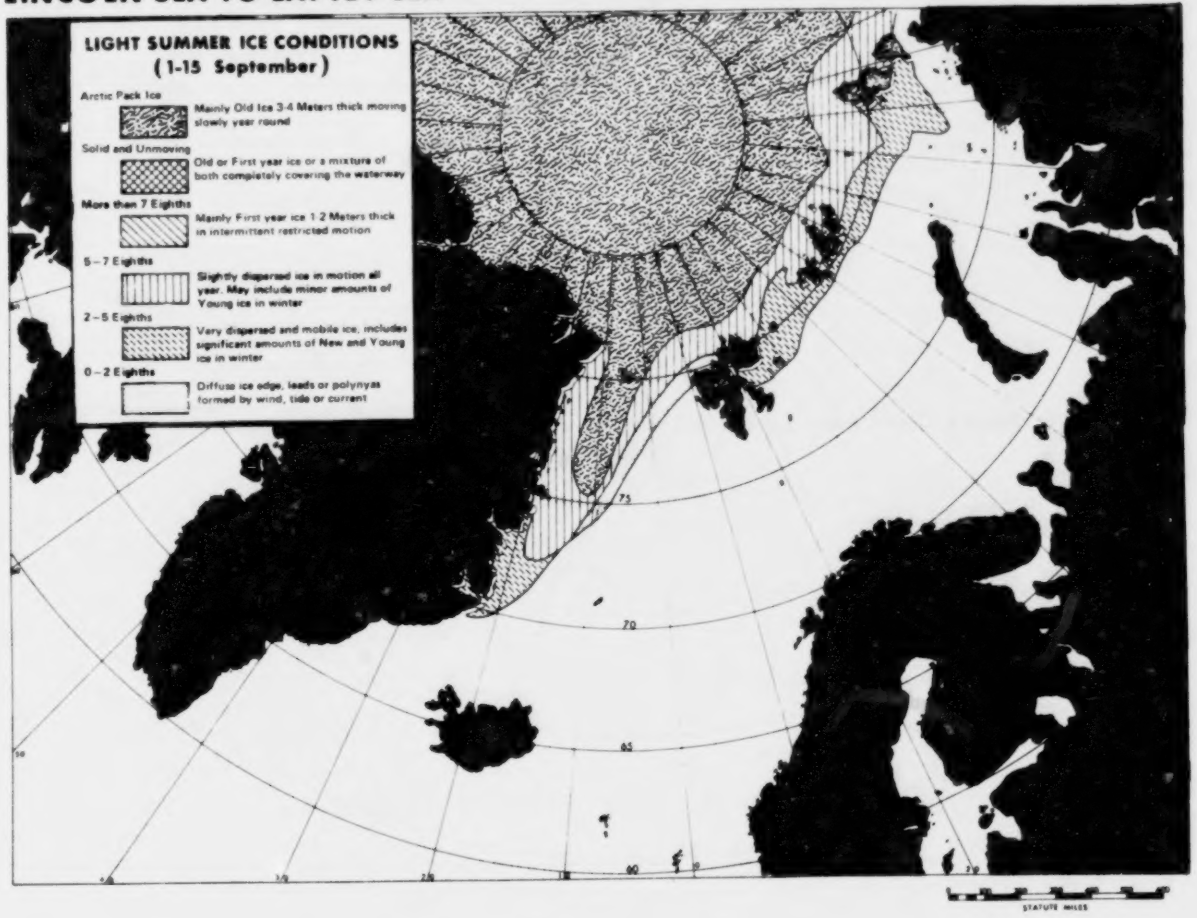

LIGHT SUMMER ICE CONDITIONS
(1-15 September)
Arctic Pack Ice
Mainly Old Ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or First year ice or a mixture of both completely covering the waterway
More than 7 Eighths
Mainly First year ice 1-2 Meters thick in intermittent restricted motion
5 – 7 Eighths
Slightly dispersed ice in motion all year. May include minor amounts of Young ice in winter
2 – 5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0 – 2 Eighths
Diffuse ice edge, leads or polynyas formed by wind, tide or current
75
70
65
60
40
30
20
10
0
10
STATUTE MILES

Figure 4 - XXIV. Heavy Summer Ice Conditions, Lincoln Sea to Laptev Sea (1-15 September)
(On facing page)

LINCOLN SEA TO LAPTEV SEA

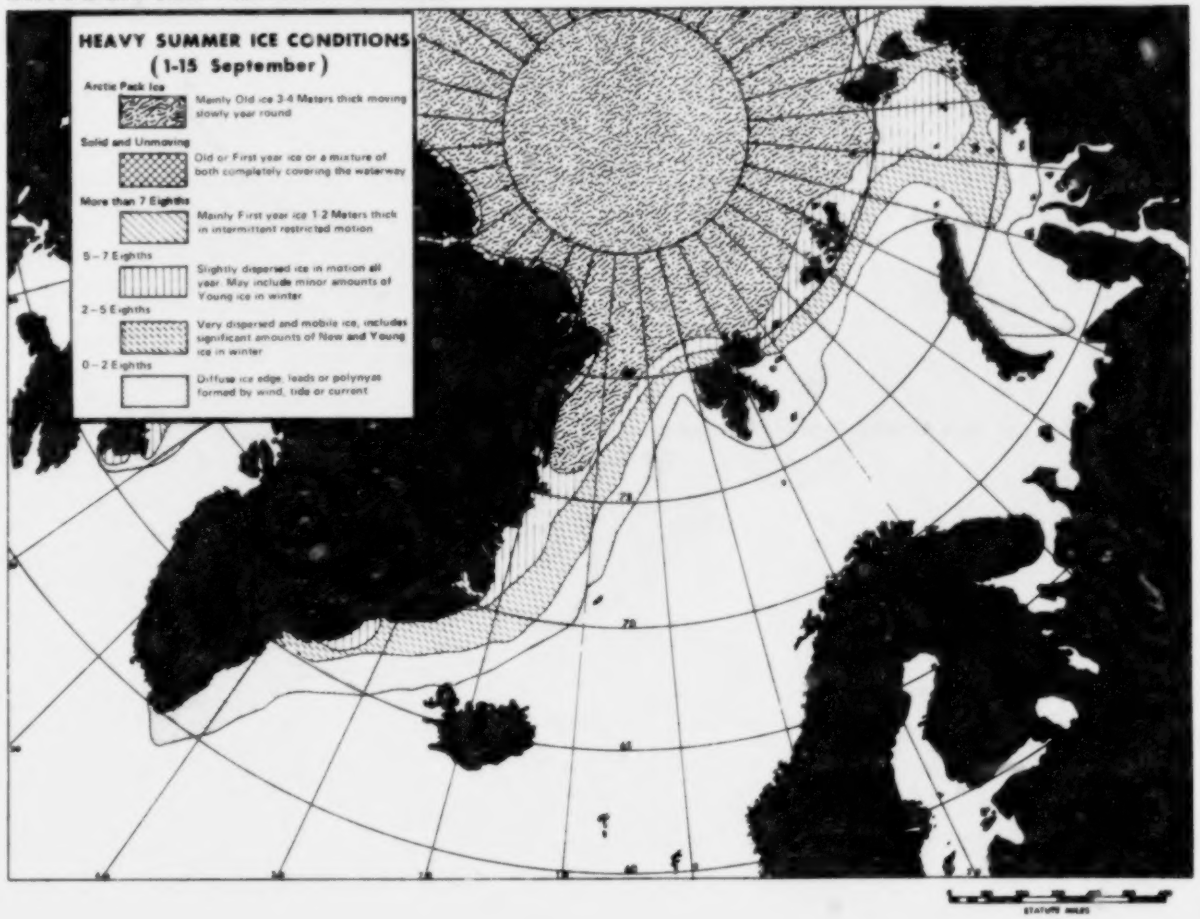

HEAVY SUMMER ICE CONDITIONS
(1-15 September)
Arctic Pack Ice
Mainly Old ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or First year ice or a mixture of both completely covering the waterway
More than 7 Eighths
Mainly First year ice 1-2 Meters thick in intermittent restricted motion
5 – 7 Eighths
Slightly dispersed ice in motion all year. May include minor amounts of Young ice in winter
2 – 5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0 – 2 Eighths
Diffuse ice edge, leads or polynyas formed by wind, tide or current
75
70
65
60
STATUTE MILES

Figure 4 - XXV. Typical Winter Ice Conditions, Lincoln Sea to Laptev Sea (February)
(On facing page)

LINCOLN SEA TO LAPTEV SEA

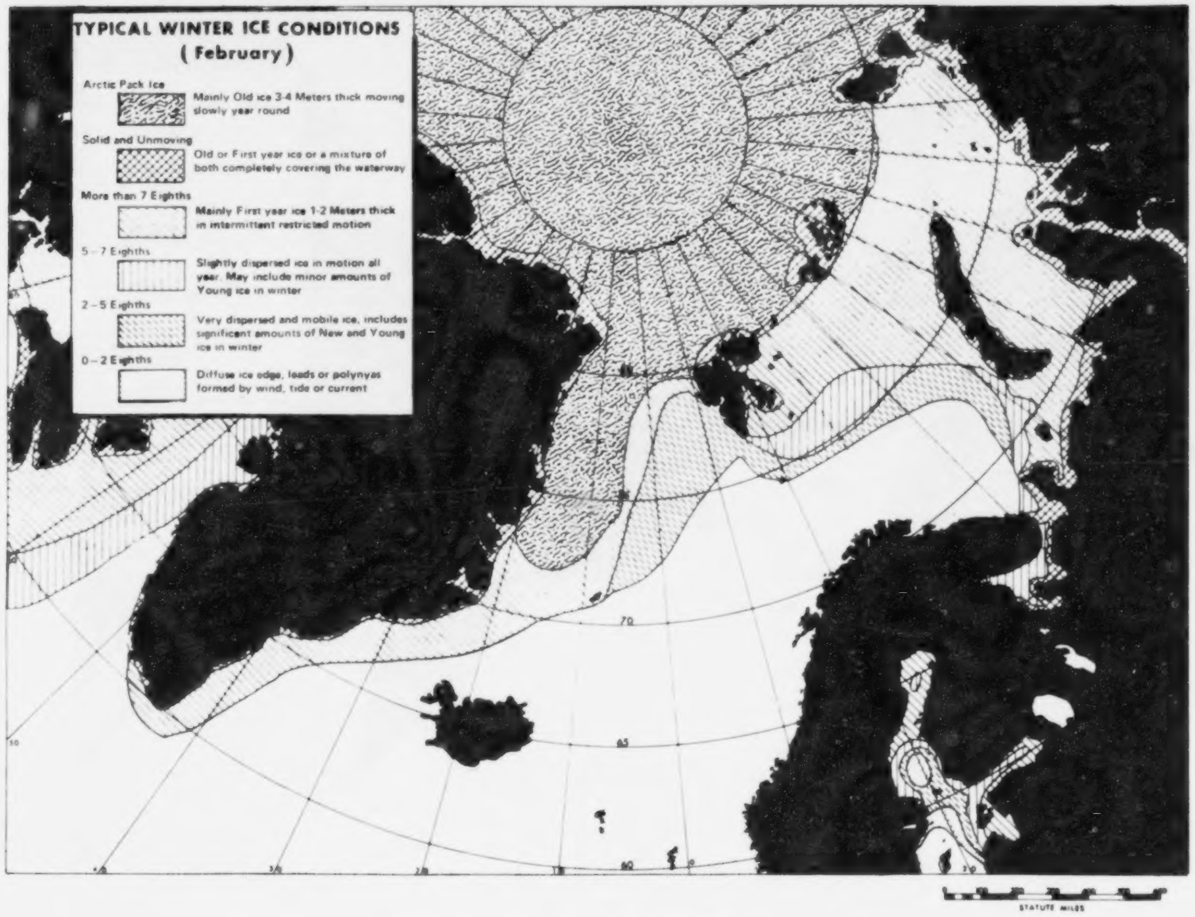

TYPICAL WINTER ICE CONDITIONS
(February)
Arctic Pack Ice
Mainly Old ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or First year ice or a mixture of both completely covering the waterway
More than 7 Eighths
Mainly First year ice 1-2 Meters thick in intermittent restricted motion
5 – 7 Eighths
Slightly dispersed ice in motion all year. May include minor amounts of Young ice in winter
2 – 5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0 – 2 Eighths
Diffuse ice edge, leads or polynyas formed by wind, tide or current
70
65
60
40
30
20
10
STATUTE MILES

Figure 4 - XXVI. Light Summer Ice Conditions, Laptev Sea to Beaufort Sea (1-15 September)
(On facing page)

LAPTEV SEA TO BEAUFORT SEA

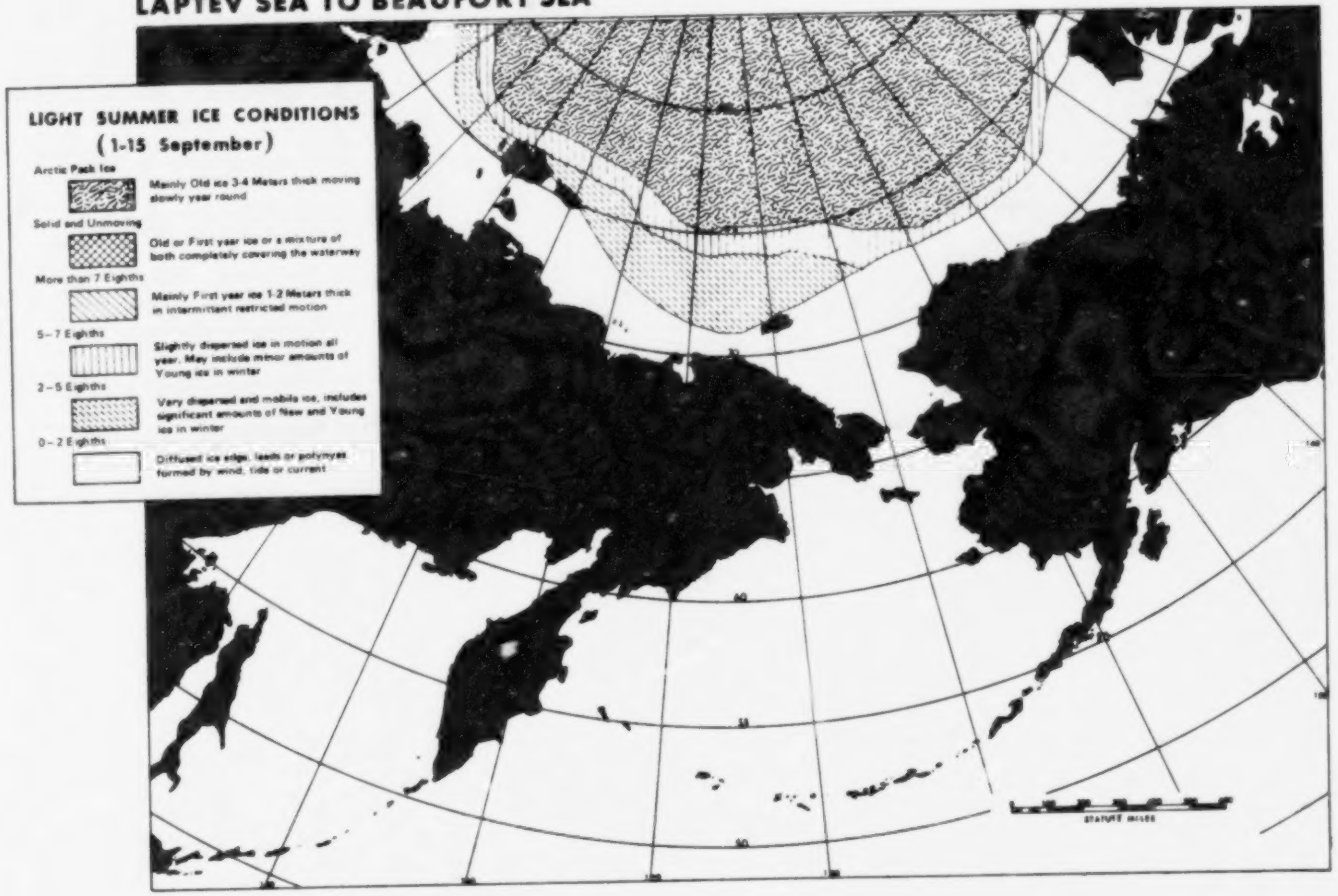
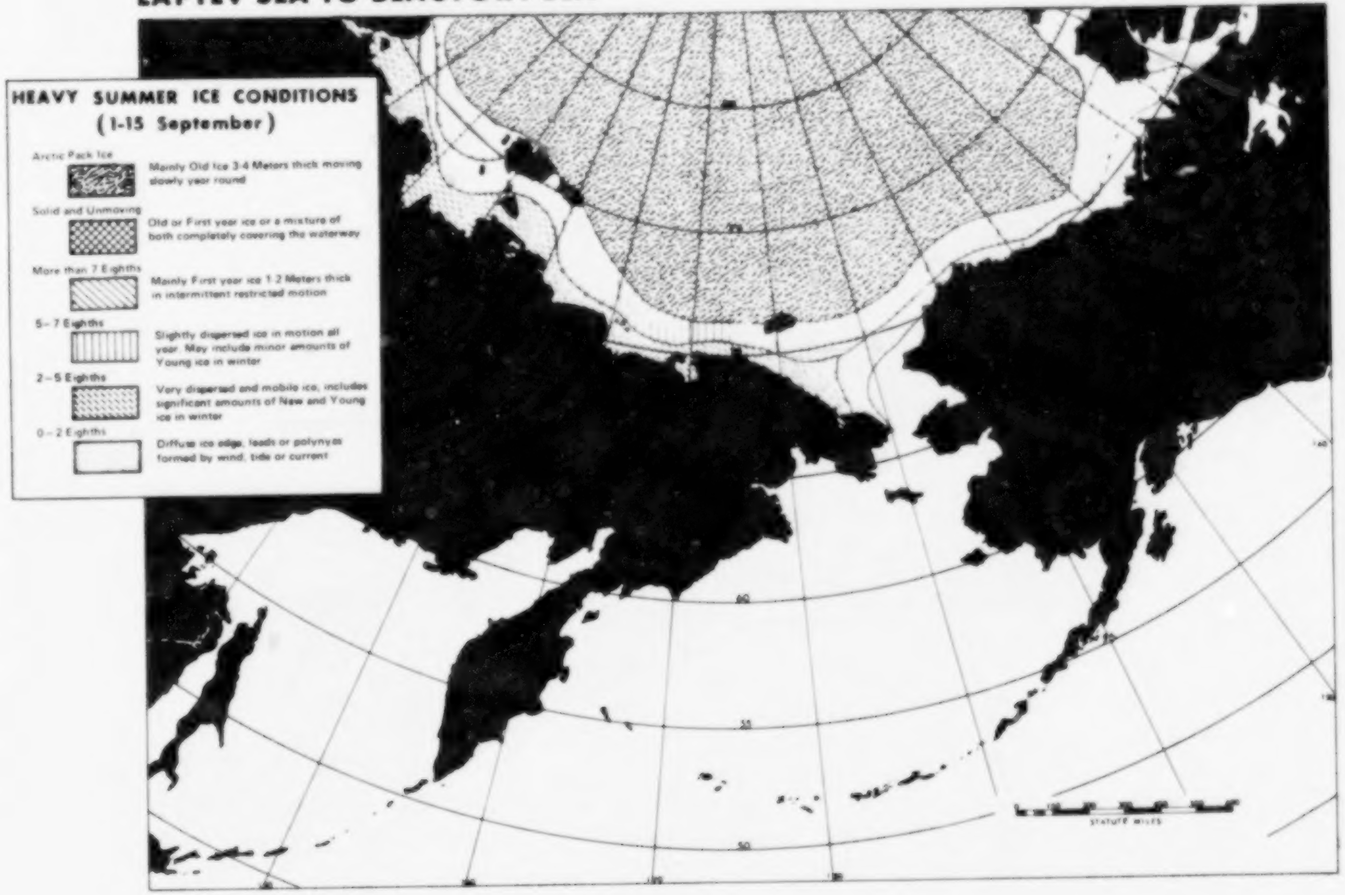

LIGHT SUMMER ICE CONDITIONS
(1-15 September)
Arctic Pack Ice
Mainly Old ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or First year ice or a mixture of both completely covering the waterway
More than 7 Eighths
Mainly First year ice 1-2 Meters thick in intermittent restricted motion
5–7 Eighths
Slightly dispersed ice in motion all year. May include minor amounts of Young ice in winter
2–5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0–2 Eighths
Diffused ice edge, leads or polynyas formed by wind, tide or current
60
50
STATUTE MILES

Figure 4 - XXVII. Heavy Summer Ice Conditions, Laptev Sea to Beaufort Sea (1-15 September)
(On facing page)

LAPTEV SEA TO BEAUFORT SEA


HEAVY SUMMER ICE CONDITIONS
(1-15 September)
Arctic Pack Ice
Mainly Old Ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or First year ice or a mixture of both completely covering the waterway
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2 – 5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0 – 2 Eighths
Diffuse ice edge, leads or polynyas formed by wind, tide or current
60
55
50
STATUTE MILES

Figure 4 - XXVIII. Typical Winter Ice Conditions, Laptev Sea to Beaufort Sea (February)
(On facing page)

LAPTEV SEA TO BEAUFORT SEA

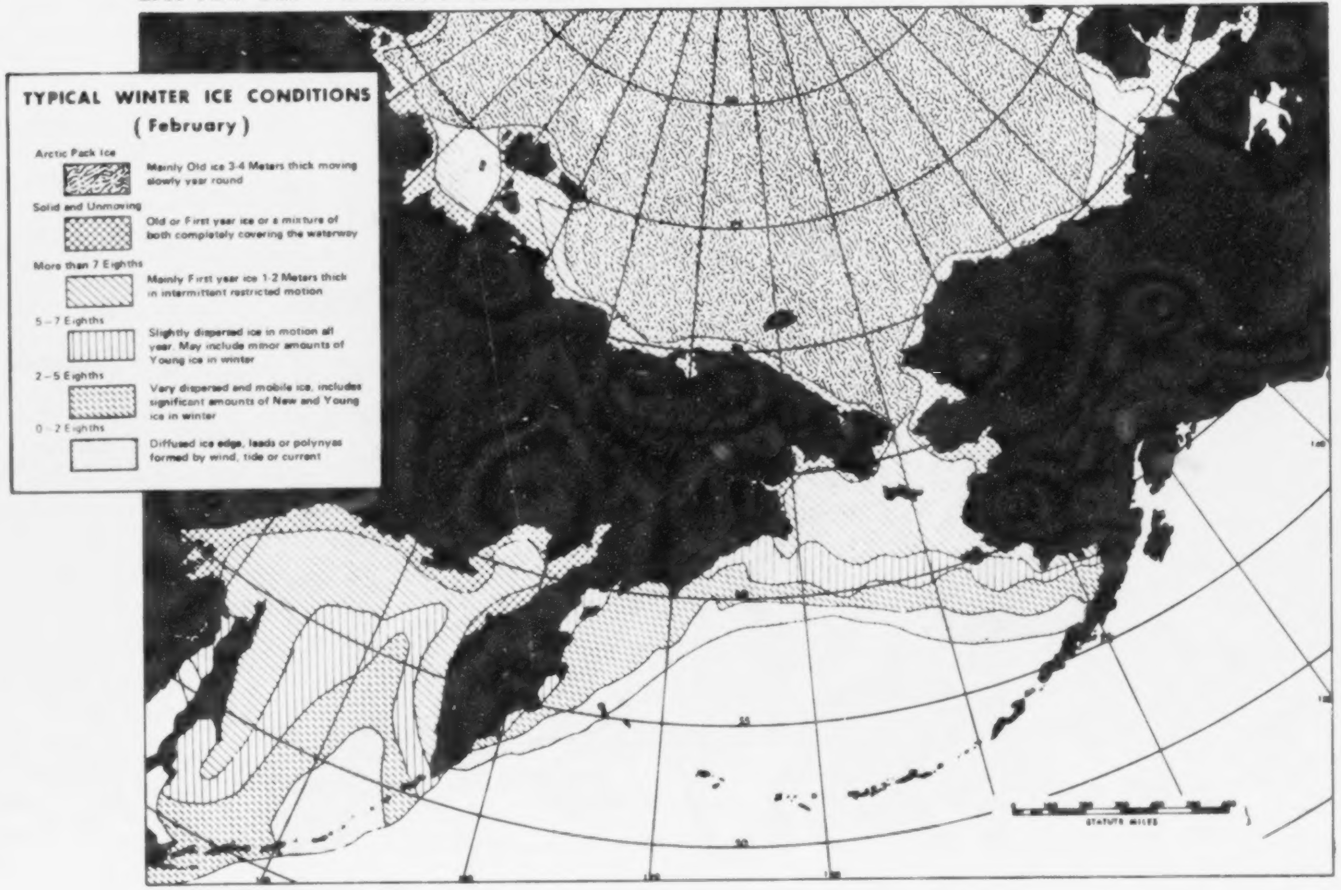
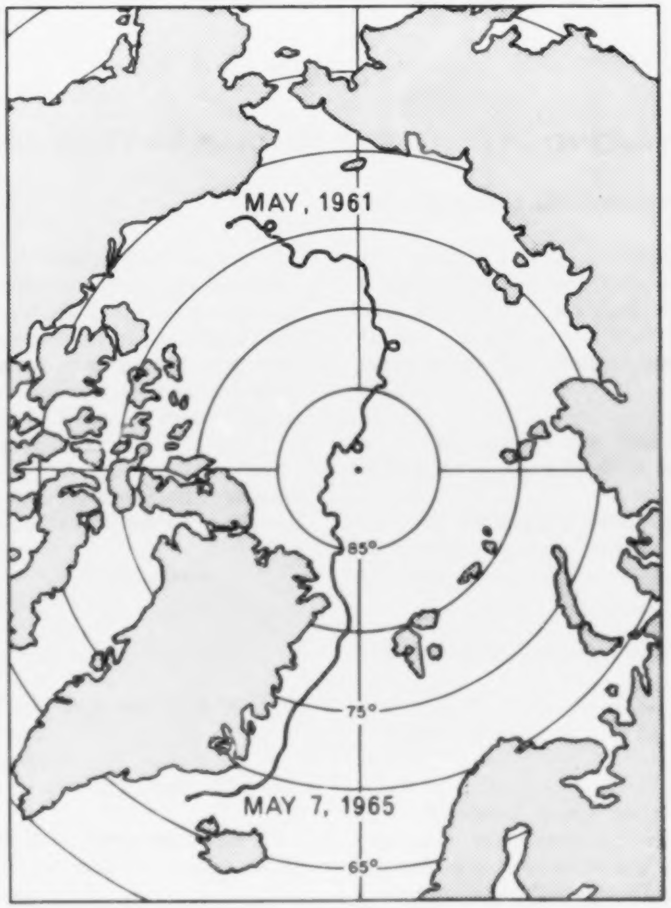

TYPICAL WINTER ICE CONDITIONS
(February)
Arctic Pack Ice
Mainly Old ice 3-4 Meters thick moving slowly year round
Solid and Unmoving
Old or First year ice or a mixture of both completely covering the waterway
More than 7 Eighths
Mainly First year ice 1-2 Meters thick in intermittent restricted motion
5 – 7 Eighths
Slightly dispersed ice in motion all year. May include minor amounts of Young ice in winter
2 – 5 Eighths
Very dispersed and mobile ice, includes significant amounts of New and Young ice in winter
0 – 2 Eighths
Diffused ice edge, leads or polynyas formed by wind, tide or current
STATUTE MILES

Figure 4 - XXIX. Drift Track of Ice Station Arlis II
(On facing page)


MAY, 1961
85°
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MAY 7, 1965
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CHAPTER 5

GENERAL PREPARATIONS FOR ARCTIC OPERATIONS

501. GENERAL

a. Weather conditions in the North Atlantic, particularly in the wintertime, can be more severe than those experienced above the Arctic Circle during the short navigation season. A ship's company accustomed to the rigours of North Atlantic operations should be able to cope with Arctic service. Indeed, the Arctic summer can be quite pleasant, with warm sunshine, temperatures well above freezing, clear skies, little wind and, because of the damping effect of ice, calm seas. There is, in fact, a threat of sunburn and a definite need for sun glasses.

b. A list of adverse climatic and other environmental conditions affecting ships and their equipment which could be experienced during Arctic operations would include:

(1) Low surface air temperatures at certain seasons.
(2) Sudden changes in air temperatures.
(3) High winds.
(4) Low sea water injection temperatures.
(5) Low humidity.
(6) Ice conditions ranging from slush and brash to solid pack.
(7) Snow, sleet and freezing rain.
(8) Fog and overcast, which are very common at the ice/water interface.
(9) Heavy seas with attendant spray in areas clear of pack ice.
(10) The possibility of heavy and rapid ice accretion, with consequent loss of stability.
(11) Abnormal magnetic conditions and low directivity of magnetic compasses.
(12) The possibility of large gyro compass errors.

502. PAINTING AND LUBRICATION

a. Against a background of ice and snow-covered land a white ship is probably the most difficult to spot. Against a sea background, however, dark gray is effective for purposes of concealment. At a distance of several miles or more, both from the air and at sea level, a ship in ice can be difficult to detect no matter what colour scheme is used.

b. The need for high quality paint and preservatives, properly applied, is as necessary for Arctic operations as elsewhere.

c. All standing rigging should be greased and lubrication systems in all exposed machinery cleaned out and filled with winter grade lubricants.

503. COVERS FOR EQUIPMENT

a. Canvas covers should be supplied for all deck winches and appliances. They are essential for open boats if their bilges are to be kept dry.

b. Waterproof covers are required for mechanical equipment exposed to heavy spray, e.g., capstans, windlasses, winches and all exposed bridge instruments. The upper blocks of boats' falls should be covered by waterproof canvas fitted to house both upper and lower blocks when in the stowed position. Canvas covers should also be arranged over the exposed parts of armament for use in conjunction with the steam heating of that equipment.

c. Canvas covers for deck winches and similar equipment should be kept securely in place except, of course, when the equipment is in use. In freezing conditions, such covers should be inspected, accumulated ice removed and lashings or other securing devices freed, so that they may be removed quickly when necessary.

504. BOATS

a. Provision should be made for the adequate stowage and expeditious handling of ship's boats so as to provide:

(1) Transportation for personnel, equipment and cargo from ship to shore.
(2) A reconnaissance capability.
(3) Lifesaving.

b. Not only may boats become damaged by ice, they can also be cut off from their parent ship by poor visibility or by drifting ice floes brought down by a change of wind or tide. Thus all boats should be equipped with emergency rations and survival kits including first aid supplies, sleeping bags, firearms and a suitable selection of hand-held pyrotechnics. In addition, all boats ought to be radio-equipped. Boats' crews should always have their cold weather clothing with them while away from their ship. For larger boats, an inflatable life-raft ought to be carried, and all boats should be fitted with radar reflectors although the usefulness of the latter may be marginal in ice.

c. Boats should be hauled out and drained when not in use, their interiors, particularly bilges and engine compartments, kept dry and their covers kept in place at all times when not in service.

d. Boats stowed in davits can be fitted with light, portable covers to prevent them from being filled with snow. Ideally these covers should extend outside the gunwhale.

e. The following additional suggestions are made:

(1) Hoisting slings may need reinforcement for rough weather handling of boats.
(2) Wooden boats should be copper-sheathed along the waterline, especially forward.
(3) Consideration should be given to the use of fibre-glass hulls for service in ice, because this type of construction is very strong and resistant to ice damage.
(4) Foam flotation material (e.g., styro-foam), which must remain impervious to both water and fuel, should be applied to boats to provide an additional measure of buoyancy in the event they are holed by ice. Large boats (generally speaking those in excess of 30 ft.) should have some form of watertight subdivision for the same reason.
(5) All boats should be supplied with repair kits to provide against hull damage while away from their ship.
(6) In Arctic service outboard motors have proved themselves to be reliable and efficient. While damaged propellers can be easily repaired or replaced, consideration should also be given to the fitting of some form of propeller guard.
(7) Keel cooling and engine manifold heaters are useful.
(8) Fuel tanks should be kept topped up in order to minimize condensation.

f. Stocks of drinking water kept in boats will not freeze and burst their containers if they are only filled to 75 percent of capacity.

505. MOORING LINES AND ANCHOR GEAR

a. Mooring lines should be kept dry and stowed under cover when not required. Manilla lines tend to freeze and suffer from dry rot in their centres if exposed to cold for long periods. Lines made of synthetic fibres (e.g., nylon, polypropolene, etc.) are perfectly suitable for cold weather service.

b. Attention is called to the effect of severe frost and cold on steel wire ropes. When such ropes are used during periods of frost or immediately after such periods, they should be examined carefully for broken wires. Particular attention should be paid to the small sizes of wire rope where the component wires are of small diameter, as the effect of frost and cold on these small ropes is more pronounced than on the larger sizes of wire ropes with larger diameter component wires.

c. Should circumstances indicate an imminent need to anchor, the cable party must be closed up in advance, and in plenty of time, to free the cable of ice. The capstan engine should be warmed through and the cable worked to and fro to rid this and the hawse of ice, thus ensuring the anchor will let go when it is released. When proceeding in waters calling for constant use of soundings, steps should be taken to make certain that anchors and cables are ice-free and ready for use at short notice.

506. TOWING

a. Ships operating in Arctic waters should be equipped and ready to tow or be taken in tow at short notice. Towing at long stay can be difficult because ice, if there is any present, is bound to get between the ships involved. Some icebreakers are equipped with a notched stern, suitably padded, in which the stem of the ship to be towed can be secured. Ships with high freeboards, however, are unsuited for this method.

b. Towing at short stay can be undertaken though the ship towed should not use her engines because of the risk of over-running and striking the towing vessel. It would be quite in order for the former to give a kick on her engines from time to time to help her follow in the towing ship's wake. Should this fail, then it may become necessary to call for icebreaker assistance or await an improvement in ice conditions brought about by a change in wind and tide.

507. SNOW AND ICE REMOVAL

a. Accretion of snow and ice can be a source of annoyance to upper deck working parties. If ice and snow continue to accumulate, the obvious result is increased top weight. This can result in a dangerous loss of stability, reduction in reserve buoyancy and critical impairment of a ship's ability to withstand damage. Other adverse effects are the increased load on decks, masts and other structures and the danger that men will slip on icy decks or be struck by falling ice from aloft.

b. There are various methods by which ice may be removed, all of which have been tried with varying degrees of success. Some of these are:

(1) *Manual.* Ice is broken away and chipped off using mallets, clubs and scrapers. Caution must be exercised to avoid damage to metal surfaces, electric cables and equipment. Ships should lay in a stock of wooden mallets, shovels, wire brooms and scrapers suitable for the removal of ice and snow.

(2) *Steam Jet.* A steam lance can be used to undercut layered ice as, for example, in freeing an anchor which has become frozen in its hawse pipe. Heavy consumption of steam, with consequent loss of feed water, tends to restrict this method.

(3) *Anti-icing Coating.* This can be used to protect comparatively small areas or items. Anti-icing compounds retard the formation of ice and contribute somewhat to the ease of its removal.

(4) *Heated Salt Water Under Pressure.* This is sea water heated to at least 50°C, or higher if possible. It is used in high pressure streams to slot, undercut and break up an accumulated abundance of ice. No attempt is made to

melt ice directly, but rather to break it up and weaken it to facilitate manual removal.

c. In general, a combination of methods (1) and (4) is still considered to be the most effective. Certain ships are equipped to supply heated salt water through their fire mains, but ships not so fitted can effectively employ fire and wash deck hoses under most conditions, provided solid streams of water at a pressure exceeding forty pounds per square inch are available. This latter method should be used with caution in conditions of extreme cold. Any tendency for the water to freeze will simply add to the ice accumulation. When using this method, scuppers and overboard drains must be clear.

d. When removing ice, care should be exercised not to damage electric cables, including degaussing cables. In some tankers, for example, degaussing cables run over the tank tops only a few inches above the deck and are easily damaged.

508. SUPERSTRUCTURE ICING

a. When severe topside icing occurs and ice continues to accumulate, despite all attempts to remove it, it may become necessary to alter course, heave-to or make for an area of more moderate weather. Icing can occur when steaming into strong winds and heavy seas and in conditions of low air and sea water temperatures. Smaller ships having low freeboards and reserve stability are particularly vulnerable.

b. The rate of ice accretion from salt water ocean spray is related to wind speed (spray is formed only when winds exceed 16 kt.), roughness of the sea, air temperature (below 1.67°C), and duration of exposure.

c. The smaller the vessel, the more serious the problem of ship icing. Any prolonged exposure to gale force winds and below-freezing air temperatures could ultimately result in the vessel capsizing. Fishing trawlers approximately 170 ft. long have capsized and sunk as a result of rapid ice accumulations on the hull and superstructure; freezing spray accumulating at a rate of two tons an hour over a period of 24 hours has been reported. Meteorological observations taken in the vicinity of Iceland indicate that storms of gale force accompanied by freezing air temperatures and lasting as long as three days may occur as often as three times a year. Sparseness of synoptic meteorological information in this area makes forecasting of such prolonged periods of gale force winds and below-freezing temperatures quite difficult.

d. Whenever air temperatures equal -2.2°C or less and winds equal 17 kt. or more, and these conditions occur simultaneously, superstructure icing is possible. However, other factors, such as the relative wind speed and sea temperature, must be taken into consideration. Generally speaking, winds of Beaufort force five and six may produce only slight icing, winds of Beaufort force seven and eight may produce moderate icing, and winds in excess of Beaufort force eight might cause heavy to severe icing.

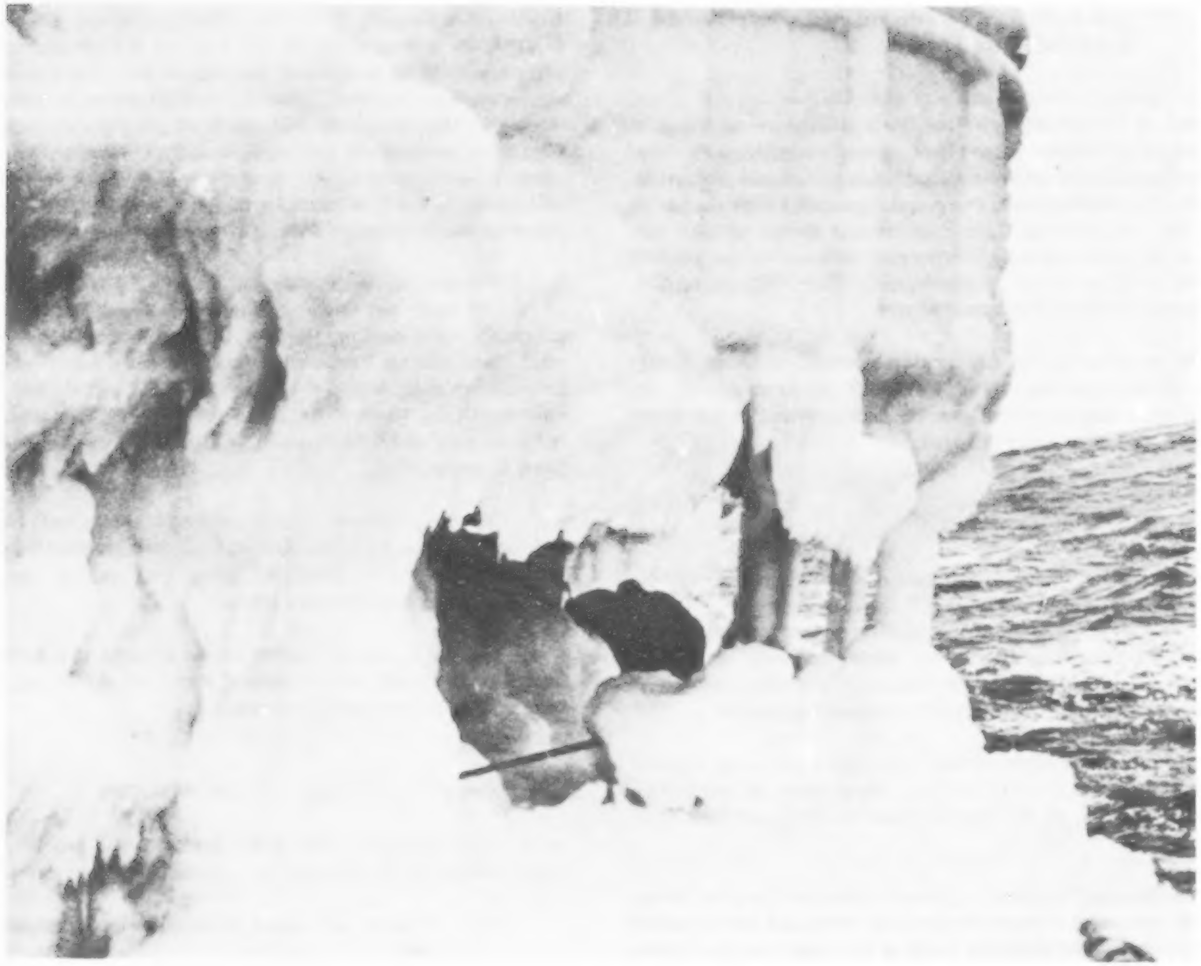
e. On flight decks of aircraft carriers, tractor powered sweepers and rotary brushes have been used with success. Care must be exercised to avoid damage to cleats and other deck fittings when using mechanical equipment for snow removal.

f. The use of aircraft engines can be effective in removing snow from around closely parked aircraft. Rock salt should not be used because of its corrosive effect on metals.

509. ICING ON CONNING POSITION WINDOWS

a. Icing of conning position windows can be a problem, but the fitting of some, or all, of the following should help:

(1) Efficient and rugged windshield wipers, designed for the task.



(2) A reliable winshield washer, using a special solvent to prevent freezing and which will cut salt rime.

(3) Heating windows electrically by means of small wires embedded in the glass. (These windows can be effective though there is a tendency for salt rime to harden on the outside which is difficult to remove if winshield washers do not function properly.)

(4) Inside window defrosters.

(5) Thermopane windows. (These are reported to be effective though, not being armoured, they could shatter when struck by heavy seas. This type of glass does not fog up on the inside.)

(6) A supply of warm fresh water and facilities for hosing down the front of the conning position as opportunity offers.

b. Clear view screens (of the "Kent" type) are of little help, being designed to cope with rain, not snow and ice.

510. CARGO HANDLING AND UNLOADING

a. Cargo should be stowed in such a manner that it cannot shift as a result of repeated impacts between the ship and the ice. It should be stowed well away from the sides of the ship thus allowing easy access to the side plating in case of damage and to permit passage of water to the bilges. Ships operating in ice should be so loaded that they will be trimmed by the stern. If in ballast, consideration should be given to flooding so as to immerse the rudder and propellers to minimize the risk of damage to them by ice.

b. The use of helicopters in handling certain types of cargo should not be overlooked. Modern machines have substantial lift capabilities and are capable of handling a significant amount of cargo quickly and effectively. They should be fitted with hoisting gear and quick release hooks for this purpose. There may be occasions when ice floes block beach unloading sites or pack prevents a ship getting close enough to employ her boats and landing craft effectively. In these and other circumstances, there is no substitute for the ubiquitous helicopter.

511. WATCHBILLS

In addition to normal watchbills, a "cold weather" ventilation organization should be prepared containing instructions for the operation of the various ventilation systems when air temperatures drop below -12°C.

512. DRYING AND STOWAGE AREAS FOR COLD WEATHER CLOTHING

Suitably ventilated spaces should be available for drying and storage of heavy weather clothing. In some ships the funnel uptake spaces may be suitable for this purpose.

CHAPTER 6

HULL, ENGINEERING AND ELECTRICAL

601. GENERAL

This chapter deals with some of the engineering and other technical aspects of northern operations which would confront the technical officers of unstrengthened ships deployed to Arctic waters when limited time is available to carry out the necessary "articization" of machinery and equipment. AEP-2 (NAVY) – *Articization and Winterization of Ships*, should be consulted in conjunction with this manual.

602. HULL STRUCTURE

a. The need for hull strengthening must be decided on a case basis. The American Bureau of Shipping, Lloyd's Register, and related NATO ship design publications give rules for hull strengthening for service in ice.

b. Forepeak shoring may be advisable, and the stem and sideplating of the forepeak should be stiffened, particularly in ships of light construction. If necessary, intermediate frames can be fitted. The stem contour plate should be doubled and, if the sideplating is only moderately thick, waterline strakes likewise. If the forepeak tank is relatively large, consideration should also be given to the fitting of an intermediate watertight bulkhead, or watertight flat, to restrict flooding should the fore-end be torn open to the sea. In small ships, reinforcing the stem with concrete is a possibility.

603. OBSTRUCTIONS

All projections from the ship's side, above and below the waterline, should be faired or removed.

604. PROPELLERS AND SHAFTING

a. Since propellers are particularly vulnerable when operating in ice, consideration should be given to the fitting of some type of propeller guard. The propellers themselves must be built of steel, steel alloy or high strength bronze.

b. Propeller material should be repairable by welding without detriment to its physical properties. Fine propeller blade edges, particularly on the leading edges, are undesirable. Propellers may be solid or built-up type. If the latter, spare blades should be carried and they should be interchangeable.

c. The installation of a replaceable weak section of shafting is not recommended as a means of avoiding propeller damage.

605. EXPOSED PIPING AND SCUPPERS

a. Overflow pipes from fresh water gravity tanks should be led inside the ship to a warmed scupper and not be allowed to drain onto an open deck. Deck edge waterways should be kept clear of obstructions so that a clear passage will exist when snow is being washed down.

b. Lagging by itself will not keep liquid in a pipe from freezing if the ambient temperature falls below the freezing point. Liquid must be warmed and kept in continuous motion; failing this, heating of all the piping lying outside the insulated structure will be necessary.

606. DAMAGE AND REPAIRS IN THE ICE

a. Ice damage can take the following forms:

(1) Bending of propeller blades.

(2) Loss of propeller blades.

(3) Steering gear damage, including the rudder head and the rudder itself.

(4) Propeller shaft fracture, possibly resulting in the loss of that propeller.

(5) Damage to stem, puncturing and tearing of plating, causing leaks in the forepart of the ship.

(6) Buckling of plating and the tearing out of rivets due to ice pressure; leading, in extreme cases, to crushing of the hull and breaking of frames.

b. As a rule, when a ship receives ice damage to her stern, repairs should not be attempted until she is first trimmed well down by the head.

c. Should the steering gear break down in a single screw ship, it may be possible to steer with the aid of two rudder pendants secured to the rudder and led to a stern capstan or cargo winch. If the rudder has been carried away completely, a similar steering arrangement may have to be improvised using a jury rudder.

d. Repairs to damage in the fore part of a ship are generally intended to prevent serious flooding. It may become necessary to raise the bow sufficiently out of the water to restrict flooding and possibly to attempt repairs.

e. Damage control parties, to be of any use in an emergency, must be trained and exercised in making such repairs.

f. Although every reasonable precaution may have been taken against damage to a ship, it is possible that damage or break-downs will occur which will be of such a nature as to necessitate major repairs. The Arctic is no place to attempt major repairs to hulls or hull fittings. In such circumstances ships should be detached and directed to the nearest shipyard or be taken under tow.

607. STOWAGE SPACE REQUIREMENTS

a. Additional stowage space will undoubtedly be required to accommodate all the additional equipment and material to be carried by ships operating in the Arctic. Space will also be required for the stowage of various compounds and liquids plus all the other special items required in cold climates. In aircraft carriers, bulk stowage of flight deck de-icing fluid may have to be considered.

b. Crew members will need extra stowage space for their gear. Space should also be set aside for Arctic clothing in living spaces or in compartments immediately adjacent thereto. Similarly, suitable facilities should be provided for the drying of heavy Arctic clothing.

608. REFRIGERATION SPACE

A substantial increase in refrigerator capacity must be considered to meet an increase in food demand. People need, and eat, more food on Arctic service.

609. FRESH WATER SUPPLY

a. To prevent ice from blocking the lower ends of suction pipes in fresh water storage tanks, they need to be surrounded by a well spaced coil of steam pipe.

b. Fresh water gravity and any similar tanks fitted in exposed positions should be steam-heated and amply lagged. Arrangements should also be made to warm the pressure switch gear if fitted. Leads of fresh water supply and drain pipes must also be lagged and steam-heated if they lie outside an insulated structure.

c. A constant check should be maintained on the fresh water supply. The use of steam de-icing will rapidly deplete reserves of fresh water.

610. SALT WATER SUPPLY

a. Leak-offs should be fitted at the ends of the fire main to assure a continuous circulation of water. These leak-offs must be at least half-inch in diameter, be well lagged and discharge either directly overboard or into a scupper with a warmed non-return flap valve.

b. Salt water hydrants fitted in exposed positions require an additional valve in the branch supply, located inside the main structure, arranged so that the exposed length of hydrant supply pipe can be drained and left empty in cold weather. Alternatively, salt water hydrants in exposed positions should be fitted with steam coil heating and be well lagged. This alternative could be used for all fire-fighting hydrants along the edge of flight decks in aircraft carriers.

c. Careful attention must be paid to the lagging of salt water supply pipes which, although not directly exposed to weather, can be subject to low temperatures, e.g., those fitted in the hangars of aircraft carriers near lift openings.

d. Careful attention must also be paid to spraying arrangements in ready-use magazines, to similar compartments in exposed positions and to magazine flooding lockers if these are located on weather decks. Steam heating ought to be fitted to all exposed runs of salt water piping.

e. Fire pumps should be capable of taking their suction from discharge side of a main engine or generator condenser or cooler so that warm water can be delivered to the fire main.

611. GENERAL INSTRUCTIONS FOR MACHINERY

a. In cold weather the Engineering Officer should ensure that all necessary precautions have been taken to prevent damage to any part of the machinery, pipes or fittings.

b. Maintaining a reasonably high temperature in the ship by raising steam periodically (in harbour, by making use of the steam radiator system), and the heating of fuel tanks, will be a safeguard against damage to machinery, etc., below the upper deck. The temperature in compartments should be carefully controlled, and, in general, machinery space temperatures should be maintained at or above 4.4°C.

c. When temperatures below the freezing point in any system are expected, one of the following procedures should be adopted to prevent damage:

(1) If no portion of the system is exposed to the weather, then the compartments in which it is situated should be maintained at a temperature above the freezing point of the liquid.

(2) Lagging alone is effective only where low temperatures are experienced for short periods. Those parts of the system exposed to the weather should be lagged and heat supplied to the whole exposed portion by means of a steam pipe under the lagging. Alternatively, heat should be supplied to some part of the system and a flow of warm liquid maintained through the exposed portion.

(3) If the procedure detailed in (1) or (2) is not possible, then the system should be drained.

d. In systems containing a mixture of glycerine and water, a check on the homogeneity of the mixture should be made by taking samples from both top and bottom of the mixing tank, and testing with a glycerometer. A homogeneous 50/50 mixture will remain completely fluid down to −27°C. A 60/40 mixture will remain fluid down to −40°C.

e. When engines having salt water cooling systems are not required for immediate use, the circulating water system should be kept empty. Engines with a fresh water cooling system should have the system charged with an approved anti-freeze solution. The raw water side of the heat exchanger system should be drained. Glycerine and water should not be used as an anti-freeze solution. Because of the fine clearances in the water pumps of both types of cooling systems, drops of water remaining after draining may cause seizure of the pump, so pumps should be warmed before turning the engines.

f. Engines required for immediate use should be kept warm by non-incandescent electric heaters or kerosene safety lamps. Under conditions of extreme cold, it may be necessary to heat lubricating oil and diesel fuel tanks.

612. EXPOSED EQUIPMENT

a. Particular attention should be given to equipment on deck, to guard against its being rendered inoperative because of congealing of the lubricant or formation of ice.

b. Canvas covers and steam or electric heaters should be used, where possible, to maintain all important equipment at operable temperature.

c. Steam heating should be used in preference to electric heating because of its economy and the fact that its use will reduce the load on electric generators.

d. Precautions should be taken to prevent the drains of steam heaters for deck equipment from freezing. Pressure gauges in exposed positions should be disconnected when non-essential.

e. Pipes of steam supply and drain systems should be clipped together and lagged. The pipes should be arranged to ensure complete drainage of the system when not in use.

f. All drain traps should be fitted with a by-pass.

g. Where traps are in exposed positions, it may be necessary under conditions of extreme cold, to remove the internal parts.

h. When removing ice from any mechanism by use of steam jet, care should be taken to avoid ingress of steam which will condense and freeze on interior working parts.

613. GENERAL INSTRUCTIONS

a. *Galleys.* The following instructions are relevant:

(1) Fuel in tanks should be warmed with heating steam.

(2) Where a water displacement system is fitted, water gravity tanks should be steam heated.

(3) Scuppers should be kept free with steam.

(4) Oil supply pipes to sprayers should be drained immediately after use.

(5) Oil supply pipes should be lagged.

b. *Domestic Boilers.* When not in use, boilers should be drained if there is a danger of freezing, and a notice "Boiler Empty" prominently displayed.

c. *Magazine Flooding Arrangements*

(1) These require frequent testing.

(2) When necessary, warm sea cocks by means of steam-heating coils.

d. *Hull and Fire Pumps*

(1) Run periodically with leak-off.

(2) When necessary, warm sea-cocks by means of a steam-heating coil.

e. *Fire Hose.* Hoses should be drained and dried when not in use.

f. *Soil Pipes and Storm Valves.* These should be kept ice-free by using a steam or hot water jet.

g. *Fire Extinguishers.* Foam type and soda-acid extinguishers should be stowed in a warm place. Arrangements should be made to ensure that the supply from the fire main for continuous foam is warm and that foam compound is stowed in a position protected from the cold.

h. *Deck Machinery*

(1) Provide efficient covers.

(2) Work periodically. Cylinders, slide chests and steam and exhaust pipes should be drained after use.

(3) Steam jets should be used to thaw out equipment not fitted with heating coils. Internal steam jets may be required for clearing circulating and other cooling water inlets when these are less than 20 ft. below the surface. When internal steam jets are used on inlets, a pressure gauge with a red mark at 15 psi should be fitted to warn of excessive pressure should the inlet be choked.

i. *Arrestor Gear and Safety Barrier System.* Heating should be provided to air reducing valves fitted in the arrestor gear and barrier system to prevent their freezing (even in moderately cold weather) through the wiredrawing of the air passing through.

j. *Telemotor Systems and Hydraulically-operated Mechanisms.* These should be charged with a 50/50 mixture of glycerine and water or national approved liquid as directed, and be tested periodically.

k. *Electric Motors and Auxiliary Machinery with Ring Oiled Bearings.* When starting these a check should be made to see that the oil rings are revolving.

l. *Pressure Gauges.* Except where they are essential, pressure gauges in exposed positions should be removed.

m. *Oil Fuel Tanks.* Gauze in vents should be removed and bonnets replaced. Heating steam should also be used.

n. *Main Circulating and other Cooling Water Inlets.*

(1) A high pressure steam jet is most effective in clearing gratings of broken ice. Care should be taken on admitting steam to avoid water hammer. A pressure gauge with a red mark at 15 psi should be fitted on the inlet tube to give warning of excessive pressure if the inlet is choked. Where steam pipe is portable it should be

removed when not required, to guard against possible access of sea water to steam pipes when shut down. Main circulators should be run as slowly as possible.

(2) The Engineer Officer should be alert for rapid changes in sea water temperature and ensure that manual adjustments are made to thermostatically controlled sea water valves if necessary.

o. *Weed Traps.* A steam jet should be provided for each main inlet weed trap where fitted. Arctic waters are free from weed, but the removal of weed trap grids may lead to damage of pump impellers by ice.

p. *Air Compressors and High Pressure Air Systems*

(1) Compressors should be run periodically and cylinder jackets drained when not in use.

(2) Drains on exposed charging column should be free of ice.

q. *Oil and Gasoline-driven Generators*

(1) These should be run periodically and cylinder jackets drained when not in use.

(2) Hose connections should be provided on sea water cooling systems to enable cooling water to be supplied from the fire main.

(3) Steam heating coils should be fitted and diesel oil ready-use tanks lagged if in an exposed position.

r. *Motor Boats.* To prevent damage to the engines and to ensure that they can be started when required, the following precautions should be taken:

(1) An external source of heat should be provided to maintain the engines and pipe systems at a reasonable temperature. It would also be necessary, under conditions of extreme cold, to warm the lubricating oil and diesel fuel tanks.

(2) When engines are not in use, or at "short notice", the sea water circulating system should be kept empty. Engines with fresh water cooling systems should have them charged with an approved anti-freeze solution. To facilitate draining the system, drain cocks should be fitted where necessary to drain water from any pockets in the system. On account of the fine clearances in the water pump, small drops of water remaining after draining may be sufficient to cause seizure of the pump if the temperature has not been above −2.2°C. To avoid damage to the pump special measures should be taken to warm the pump before turning the engine.

(3) The capacity of electric batteries is considerably reduced at very low temperatures and it may be found necessary to use both working and spare batteries connected in parallel. The electrolyte of a fully charged battery freezes at −50°C, and that of a discharged battery at −10.6°C. Batteries should be maintained at full charge by means of a trickle-charger. Where charging facilities are not available at boat stations, an external source of heat should be applied to the batteries.

(4) Full use should be made of devices fitted to assist cold starting of diesel engines, such as heater plugs, ether, etc.

614. STEAM PIPES AND STEAM HEATING

a. *Piping*

(1) Steam heating mains should be provided throughout the ship as required, together with the appropriate shut-off valves using steam at reduced pressures, usually about fifteen pounds per square inch. These mains require cross connections from the boiler rooms so that any boiler can supply the required steam. Steam heating mains must, however, be so arranged that they can be isolated into sections, each being supplied from the corresponding main machinery unit. Generally speaking, steam heating drains should be returned to the unit from which the steam originated; return to any other unit would not be acceptable under normal circumstances. In cases where a drain is used infrequently, e.g., for draining a length of pipe when opening up steam to the system, it would be acceptable to lead it to a local drainage or sump if the alternative involved a long and complicated run of piping.

(2) Where both saturated and super-heated steam systems are fitted, the drainage main should be common to both systems. The drainage main must be suitable for higher temperatures.

(3) Each branch drain must have a non-return valve to prevent interconnection between the saturated and super-heated systems. The drainage main should be arranged to drain any machinery unit system and be fitted with an isolating valve at each main bulkhead.

(4) All steam heating fittings should have isolating valves enabling them to be shut off from the heating and drain systems.

(5) All branches from the steam and drain mains must be provided with isolating valves at the mains and at individual equipment. In this way, local defects can be corrected without having to shut off large sections of the supply or drainage systems.

(6) Steam supplies to calorifiers, galleys and other equipments in continuous use in any climate should be arranged to reduce to a minimum the amount of ship's heating system served when general ship's heating is not required.

(7) Precautions must be taken to prevent the drains for steam heating of deck equipment from becoming frozen. The steam supply and drain pipes should be clipped together and lagged and the pipes so arranged that the system can be completely drained when not in use. All drain traps should be provided with a by-pass. Except where specifically ordered (e.g., under the gratings in exposed lookout positions), steam pipes and heating pipes require lagging if they lie outside the insulated structure.

(8) Steam pipes should be arranged with ample bends to take up expansion.

(9) Continuous automatic drainage arrangements must be provided for all locations which form water pockets, or "dead-ends", when valves are closed.

b. *Exposed Positions.* Steam heating arrangements must be fitted to all exposed control positions, including any open conning position on the bridge, lookout sites and control site positions, arresting gear and safety barrier gear control positions, catapult control positions, deck landing control officer's position and any similar control position not permanently enclosed.

c. *Air Vents and Ventilating Openings.*

(1) Generally speaking, air vents and ventilating openings which are protected with gauze against the transmission of flash, should retain the gauze in place but be fitted with steam coils to keep them free of ice. Such coils should be shrouded from the direct influence of wind, snow and spray.

(2) Steam heating is not required at the air escapes of oil fuel and diesel oil tanks. When approaching Arctic waters, gauzes should be removed from these tanks and their bonnets replaced.

(3) Canvas covers should be provided for closing ventilation openings where considered desirable.

d. *Ready-use Fuel Tanks.* Any exposed tanks containing liquid, e.g., ready-use diesel and lubricating oil tanks, which are likely to be exposed to low temperatures, should be heated by a steam coil and lagged overall.

e. *Galley Equipment.* If a galley is exposed to weather and likely to reach a low temperature when its cooking equipment is not in use, steam heating must be fitted to ready-use oil and water tanks, and to any equipment which may contain water and to which heating arrangements have not already been provided.

f. *Hydraulic and Reserve Feed Tanks.* If these tanks are in positions where they may be exposed to freezing temperatures, they will require steam heating.

g. *Scupper Non-return Valves.* The lower length of every scupper should be heated, the steam pipe being lagged to the scupper pipe, from the ship's side upwards for a height of four feet. The non-return valve, if fitted, must be included in the heated length.

h. *Aircraft Lubricating Oil System.* In addition to storage tank heating, steam pipes should be run adjacent to the entire aviation lubrication delivery system. Such steam pipes must be lagged together with the oil pipes and also the heating drains where applicable. Whether or not there is more than one source of steam for this system, the drains should, in most cases, be returned to the machinery unit from which the steam originated.

i. *Inlets and Discharges*

(1) A special sea chest, designed to remain ice-free, must be provided for emergency fire pump suction.

(2) Important inlets, which pierce the ship's side less than twenty feet below the average cruising water line, should be fitted with steam nozzles arranged to direct a jet of steam onto gratings for ice clearance. The inlets concerned would be magazine flooding, fire and bilge pumps, hull and fire pumps, hangar spray pumps and electric generator circulating water inlets. Main circulating water inlets should be treated similarly, both as regards the grating and the weed trap, if no such provision has already been made.

(3) If any essential sea inlet or discharge valve is fitted in a remote part of the ship in a compartment where water may collect, they must be heated by steam coil if there

is any likelihood of their freezing in one position due to ice forming on the valve spindle.

j. *Heads.* Steam heating arrangements, in addition to steam-heated ventilation, should be fitted in heads in exposed positions where there is any risk of water freezing.

k. *Flight Deck Machinery*

(1) Flight deck machinery which is fitted in unusually exposed positions must also be fitted with steam heating arrangements, e.g., hydraulically operated parking chocks at the extreme fore-end of the ship, or parts of the catapult fitted immediately under the flight deck.

(2) No such arrangements are required for ordinary hinged mechanisms which are adequately provided for by use of low temperature lubricants and de-icing compounds. No steam pipes should be fitted in positions exposed to weather, unless they are lagged to the item they are warming. Pipes containing hydraulic fluid do not generally need to be heated – a mixture of 50 percent glycerine, 50 percent water, by volume, will remain completely liquid down to −29°C, and a 60/40 mixture down to −40°C.

615. ELECTRICAL HEATING

a. Consideration might be given to the use of electric heating in certain remote positions where it would be uneconomical to run steam piping. Electric radiators could also be fitted adjacent to each pump unit of aircraft lifts. Radio battery cupboards in exposed positions should also be provided with heating when the air temperature falls below the freezing point.

b. Switch sockets for use with electrically heated clothing must be fitted in exposed positions, e.g., lookout positions and signal decks.

c. Exposed control positions for cranes should also be provided with suitable electric heating.

616. VENTILATION

a. Ventilation and heating systems must be cleaned and tested before entering cold regions.

b. Steam heating will be required in the ventilation supply to all living spaces, messes, dining rooms, cabins, wardrooms, recreation spaces, offices, sick bays, workshops and vital action compartments. In the case of large fans supplying a number of living and working spaces, an attempt must be made to achieve the following:

(1) *Preheating.* Steam coil preheaters should be fitted in supply tanks as close as possible to the weather deck or ship's side inlet. These preheaters must be capable of heating the air intake, at a low fan speed, to 7°C.

(2) *Compartment Heating.* Additional heating of compartments should be supplied by "booster" heaters in the trunking, each booster heater being arranged to serve groups of compartments having the same heating requirements.

(3) No special preparation for Arctic service will be necessary for equipment fitted in compartments already insulated and fitted with heated ventilation.

617. INSULATION

a. In general, the weather boundaries above the light water line of all living and working spaces should be insulated. The weather boundaries of other compartments may be similarly insulated if the contents or functions of the compartment require it to be protected against extreme cold. Weather boundaries include weather decks, ship's side, superstructure bulkheads, etc. Overhanging and closed compartments (e.g., galley deck), compartments in aircraft carriers over the table deck, boat stowage openings, quarterdecks, etc., require insulation on the underside of the deckhead. All beams, frames, girders and stringers on weather boundaries need to be insulated, as do the following:

(1) All storerooms or compartments containing material such as stores and food, or in which piping is located.

(2) All enclosed lookout stations and conning positions.

(3) All ventilation supply trunks between inlet and heater or preheater.

(4) In the way of side scuttles, doors and other fittings, insulation should be so arranged that it does not interfere with these fittings and that the edges of the material are protected from damage. It should also be applied to steel doors opening onto weather decks.

(5) *Heads.* Weather boundaries should be coated with insulating material but the lagging should terminate twelve inches above the deck to avoid damage when washing down.

(6) *Bathrooms and Laundries.* These are spaces which require insulation of a special waterproof type.

b. Thermal insulation ought to be applied to the shell and bulkheads behind and above switchboards if such areas suffer from condensation. All cold weather piping and equipment such as fire, sanitary and fresh water systems, soil pipes and fresh water tanks should be insulated where damage to equipment or discomfort to personnel may result from dripping condensate. All ventilation supply and exhaust ducting and heaters, including flanges and joints, must be insulated to prevent sweating and heat loss.

618. TANK VENTS

Oil tank vents which are normally exposed should be modified or relocated to protect them from freezing spray and from icing. Where practicable, vents, other than those from oil tanks, need to be relocated below decks.

619. SIRENS AND AIR HORNS

Siren drains should be coiled around the body and the horn of the siren, and the whole well lagged. Arrangements must be made so that the steam trap can be by-passed, when required. Heating arrangements should also be provided for air horns, particularly in the vicinity of the reeds or discs.

620. LOOKOUT AND CONNING POSITIONS

All exposed watch-keeping positions must be enclosed to afford maximum protection from the weather. Temporary shelter may need to be erected in the eyes of the ship for ice lookouts.

621. SHORT STAY IN HARBOUR (UP TO 48 HOURS)

a. *Main Engines.* When necessary, the main engines should be moved a few turns every few hours to keep propellers and rudder free from heavy ice.

b. *Sirens.* If steam operated, the steam should be shut off and the siren thoroughly drained.

c. *Boilers.* In general the temperature of the boiler rooms and of water in the boilers, should not fall below 5°C.

622. LONG STAYS IN HARBOUR AND REFITS IN COLD WEATHER

a. *Main Engines.* Main steam lines and exhaust lines should be carefully drained. Engines and shafts should be moved daily.

b. *Turbines.* Drain the gland steam system and main condenser and coat exposed journals with preservative grease.

c. *Reciprocating Engines.* All cylinders, piston rod and valve rod packing boxes, and all water services should be drained.

d. *Auxiliary Machinery.* Steam and exhaust lines to be drained. All cylinders and valve chests should be drained and drain plugs on water pump barrels removed for draining. Piston rods, valve gears, etc., should be kept in a state of preservation. All rotating engines should be moved daily.

e. *Lubricating Oil System.* Circulate periodically through the purifier heater if one is fitted.

f. *Stern Glands.* In very severe weather conditions, a supply of warm water from the fire main should be provided for steam heating use if fitted.

g. *Pressure Gauges.* To be disconnected at the gauge, should the temperature in the compartment fall below a reasonable temperature, i.e., 5°C.

h. *Steam Capstans, Windlasses and Winches.* Cylinders and valve chests should be drained. Steam and exhaust lines to be drained and the engines moved daily. Guides, piston and valve rods require coating with anti-freeze paste or non-freezing mineral oil mixed with black lead, if situated on an open fore deck. Under extremely cold conditions the capstan should be run continuously.

i. *Steering Engines.* Compartments must be kept as warm as possible. Cylinders and valve chests should be drained thoroughly and engine parts put in a state of preservation.

j. *Rudder and Steering*

(1) A high temperature to be maintained in the compartment by use of electric radiators or steam radiators where fitted.

(2) Work daily after first ascertaining that ice under the stern is broken.

k. *Condenser, Feed Lines, Feed Heaters, Drain Coolers, Distillers and Lubricating Oil Coolers.* These should be drained if reasonable temperatures cannot be maintained in the compartments.

l. *Main and Reserve Feed Tank.* The tanks to be emptied and the system drained if the temperature falls in the compartment.

m. *Hot Water System, Sanitary System and Drain System.* These should be drained thoroughly if it is impossible to maintain temperatures in the ship at reasonable levels.

n. *Fresh Water Tanks.* Tanks should be emptied where practicable. Tanks required for use, and not fitted with heating coils, must be inspected periodically to ensure that ice, which may choke the suction, is not forming inside. Ice is only likely to form if the weather is exceedingly cold for a considerable period and the ships are surrounded by ice and the water consumption is low. If ice does form it should be cleared by use of steam or warm air.

o. *Fire Main.*

(1) Drain the system if the possibility of freezing exists.

(2) Shut off the water supply at dockside and do not permit hoses to freeze.

p. *Steam Heating System.* This should be connected to shore, or another ship if possible, and all compartments kept warm. If no heating system is fitted or no steam is available, coal or oil stoves should be procured. The heating system must be drained if a reasonable temperature cannot be maintained.

q. *Fresh and Salt Water Systems.* If coupled to a shore supply, valves on the end of the line should be kept open so that water in the pipes is kept moving. If not connected to shore supply, lines must be drained and gravity tanks emptied if they cannot be heated.

r. *Domestic Boilers.* When not in use, boilers should be drained if there is danger of freezing.

s. *Emergency Fire Supply in Drydock.* With an emergency fire hose coupled to shore, the valve on dockside should be tried daily for water supply with the hose disconnected. The hose must be kept dry to prevent freezing.

t. *Steam Heating Coils in Fuel Oil Tanks.* These should be drained if the tanks are empty.

u. *Ring Oiled Plummer Blocks and Bearings.* Before getting under way a check should be made to ensure that oil is fluid enough to allow ring movement; if not, then hot oil ought to be added.

v. *Bilges.* All bilges should be pumped out before entering drydock.

w. *Echo Sounding Hull Units.* Tanks should be emptied and refilled with a thoroughly mixed solution of one part glycerine to three parts water. Systems must not be filled with solutions which are not homogeneous, as the result will be increased transmission and reception losses.

623. FRESH WATER

a. Ships distilling their own water occasionally encounter concentrations of plankton which yield a volatile oil giving a fish odour and taste. This condition can be recognized by the deposition of green scale, instead of the usual tan scale, on the tubes of the distilling plant in submerged coil distilling installations. No harmful effects have resulted from drinking such water.

b. Fresh water tanks should be filled to 90 percent of their capacity, to allow for expansion in the event of freezing. Potable water might best be used from the forward tanks first, due to the risk of leaks developing there from ice damage. All water tanks adjacent to the outer skin of the ship must be equipped with heating coils.

624. GAS CYLINDERS

a. Pressure in compressed gas cylinders subjected to cold will drop considerably and may be insufficient for practical use. In such circumstances they may have to be warmed, but extreme care must be taken to ensure that such cylinders are *not* overheated.

b. Bottled gases should be stowed inside since, if they are used directly from an outside stowage in cold weather, as much as 75 cu. ft. of volume can be lost.

625. PREPARATIONS APPLICABLE TO AMPHIBIOUS AND AUXILIARY CRAFT

a. *Landing Ship (Dock)*

(1) Shell connections for well-deck flooding and drain

piping should be relocated to a position well below the waterline.

(2) Existing lubricating oil storage and sump tanks, adjacent to ship's side, will require heating coils. Additional heating coils may also need to be installed in fuel tanks to keep the oil at its prescribed temperature.

b. *Landing Ship (Tank)*

(1) Bow and stern strengthening, including wood sheathing, is required.

(2) Special high strength manganese bronze propellers will probably be required in lieu of steel propellers.

(3) Douglas Fir sheathing should be installed forward from the turn of the bow and covered with half-inch steel plate. Sheathing abaft the turn of the bow may be omitted. Bow doors require a half-inch steel plate quilted over the aforementioned wood sheathing. Bracing timbers should be fitted between the bow doors and the hull, adjacent to the bottom of the ramp. Flaps on bow doors must be welded shut and otherwise made an integral part of the door. Bottom plating in the way of the bow voids require strengthening to prevent rupture from below. The hull, forward of the propeller guards, should also be strengthened to prevent puncture when the stern swings into ice.

c. *Landing Ship (Utility)*

(1) The enclosed conning position should be extended to accommodate the additional radio equipment required for Arctic operations.

(2) Two portable jacks to be provided to ensure positive starting of the bow ramp in cold weather.

(3) All water piping which is normally full should be run through heated spaces. Failing this it must be lagged. Where exposed to the weather, it should also be fitted with a cut-off valve and be drained in freezing conditions.

(4) Drains to be fitted in the bottom of the capstan engine (anchor engine) gasoline tank to permit drainage, thus avoiding the freezing of any accumulated water.

(5) Cut-out valves and drains to be installed inside the ship for all fire hydrants exposed to the weather.

(6) For thawing frozen scuppers, a line should be taken from the hot water heating system and be coiled around the overboard discharges where they join the shell plating. This installation must also be insulated.

(7) Provision should be made for the introduction of warm water into the fire main for de-icing purposes.

(8) Heating elements should be installed in living space ventilating systems so that air may be heated to 18°C when outside air is −12°C.

(9) Electrically operated windshield wipers should be installed in the conning position.

(10) All ventilating louvers to be fitted with snow baffles.

d. *Landing Craft (Medium)*

(1) Keel heat exchangers and a complete fresh water cooling system to be installed.

(2) Coolant heaters, with arrangements for keeping engines, batteries and a running tank of fuel at a temperature of approximately 21°C, to be fitted.

(3) Bulkheads and the underside of the engine room deck should be insulated.

(4) Battery capacity to be increased. Shore connections should be installed for charging batteries. Battery charging generators to have their capacity doubled.

e. *Landing Craft (Vehicle and Personnel)*

(1) Keel heat exchanger and a complete fresh water cooling system, including a coolant heater, to be installed.

(2) Battery capacity, and the capacity of the battery charging generators, would need to be doubled.

(3) An external power source should be fitted for engine starting.

626. MAIN ELECTRICAL SUPPLY

a. Electrical installations, built into a ship in accordance with standard naval practice, should be adequate for Arctic service without major modifications. Only minor additions to the distribution systems and equipment, to accommodate new power consuming equipment, may be necessary.

b. Added power distribution should be supplied directly from the main generator and distribution switchboards. However, small auxiliaries, wherever practicable, ought to be supplied from the distribution boxes or existing distribution panels.

c. It is not the effect of extreme cold on machinery and equipment that makes for difficulties, but the substantial increase in demand for electrical power. Additional spaces must be heated, electrically-driven mechanical equipment run at frequent intervals to prevent freezing, plus a host of other demands upon the ship's electrical resources.

d. Electrical equipment must be kept in peak operating condition. Unlike its mechanical counterpart, electrically-driven apparatus should not be started and motor run simply for the purpose of warming up or testing. The effect of such a warm-up will soon be lost unless it is run for a long time and at frequent intervals. Unnecessary starting of a motor imposes a strain on insulation because of the expansion and contraction from heating and cooling. In an emergency, however, electric motors may be warmed up and kept running as necessary. Motor controllers in exposed positions, such as controllers for winches or boat davits, should be provided with heaters inside controller enclosures and be inspected daily to ensure they are operating.

e. A careful watch must be kept for corrosion of electrical gear, due to condensation, particularly of relay contacts and switches. Spark plugs, magnetos, ignition harnesses and other electrical leads are all susceptible to condensation.

f. Rotating electrical equipment, motors, inverters, generators and alternators will require special maintenance and low temperature lubrication. Even when this is done, slow starting and heavy loads may be expected. Electrical radiators, or hot air blasts from a hand heater, should be provided for pre-heating

627. LIGHTING

a. Lighting installations, if in accordance with naval practice, will be perfectly satisfactory for Arctic service. Only those modifications necessary to provide suitable lighting in new or redesignated spaces should be necessary.

b. Suitable searchlights, if not already fitted, would be useful for floodlighting the ice area in the path of a ship, should navigation at night become essential. Preferably such lights should be sited in the eyes of the ship so as not to blind bridge personnel.

628. BATTERIES

a. Storage batteries present a problem. If they are to be used in equipment subjected to temperatures below −2°C they should be specially designed for the task. However, such low temperature batteries are not only costly, but their storage life is short. Accordingly, they should be prescribed when nothing else will do, and in the meantime they need to be stored refrigerated.

b. Care should be taken to keep all lead-acid batteries fully charged. Capacity of storage batteries falls off rapidly with a drop in temperature.

c. Auxiliary power units are essential for cold weather engine starting and for pre-flight line checks. Electrically-heated flying suits, and other electrical devices, should not be operated unless a suitable generator is being kept in operation.

d. If aircraft engine starting batteries are fitted in exposed positions, they need to be housed in asbestos-lined containers fitted with electric heating arrangements for use in freezing temperatures.

e. Portable generators should be used at every possible opportunity to build up the charge of storage batteries. Whenever battery acid specific gravity falls ten points below name plate rating, it must be recharged at once and every effort made to keep it that way. Batteries in ship's boats should be treated in the same manner.

f. To cope with this additional battery maintenance, the allowance of battery acid carried will need to be substantially increased.

g. All aircraft should be fitted with quick release equipment for the removal and installation of storage batteries. When feasible, it is preferable to remove them from the aircraft and hold them temporarily in a warmed storage space until required.

h. To assist engine starting in motor boats and landing craft, a bank of batteries, and a battery charging motor generator, should be available. Low voltage outlets should also be available on the flight and hangar decks of aircraft carriers to charge aircraft batteries and to augment their output for starting piston engines.

i. Mobile power sources, using batteries alone or in combination with an engine-generator set, must be stowed in heated spaces.

CHAPTER 7

WEAPONS

701. DE-ICING

a. Washing with warm water, fresh if it is available, is the preferred method for removing accumulated ice on metal shields and protective covers. Chipping, or the use of torches, should be used only in exceptional circumstances and never in the presence of ammunition. The use of chemicals for the prevention of ice formation on weapons must be prohibited. (See also Chapter 5, Article 507 – Snow and Ice Removal).

b. Maintenance procedures and training of maintenance personnel must be stressed during warm weather operations so that de-icing systems are not permitted to deteriorate from lack of operation or be damaged through ignorance and neglect.

702. GUNS

Factors which influence the firing of guns at low temperatures include a tendency for metals to fracture at low temperatures, and the effect of low temperatures on propellants and lubricants and on fluids in recoil, cooling and transmission systems.

703. COVERS

On mounts appropriately designed, all openings into mountings or breech mechanisms should be fitted with removable canvas covers, including separate covers for gunsights and breeches of guns. Canvas skirts secured to gun shields, and reaching to the deck, will be required, care being taken to ensure these will not interfere with the movement of the mounting.

704. TRANSFERABLE GUN MOUNTINGS

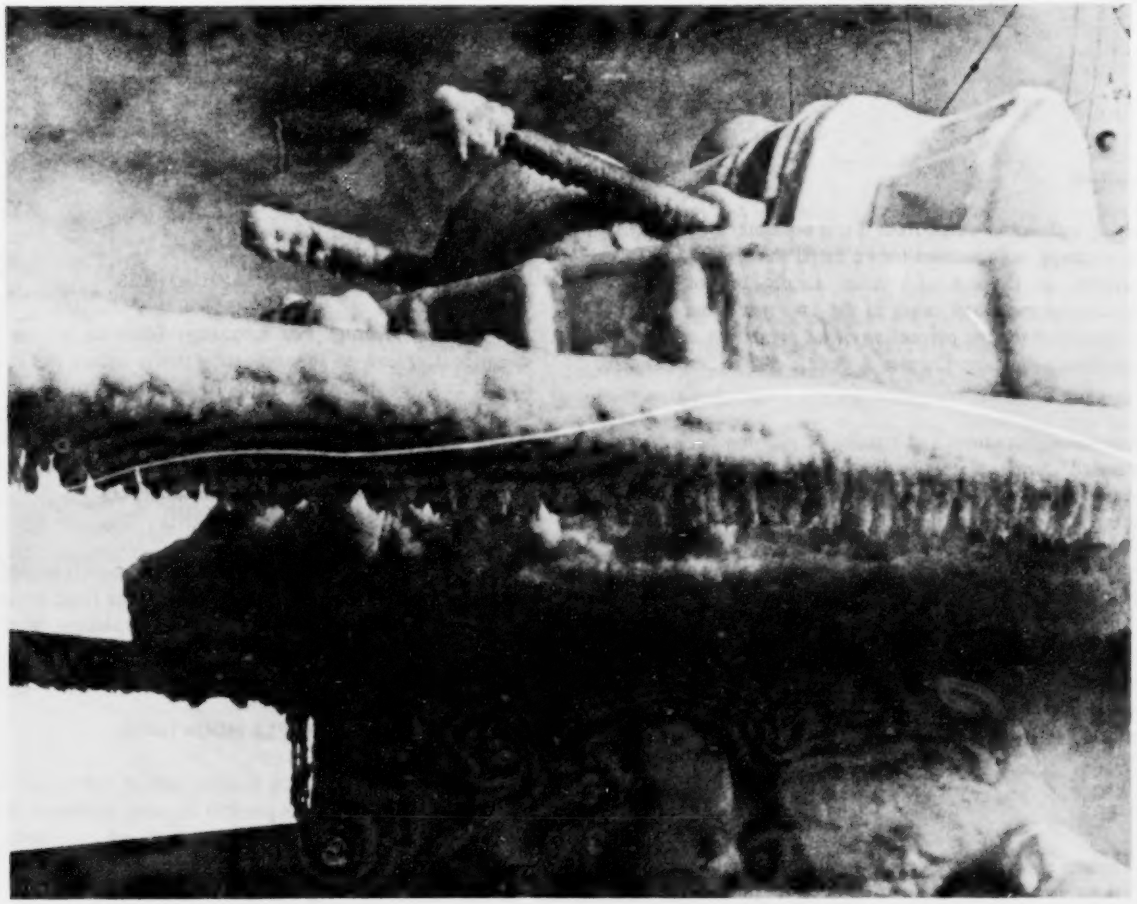
a. *Steam Heating.* For mountings fitted on tubular supports, a steam heating coil of approximately twelve square feet in surface area should be fitted inside each support, as close as possible to the training base. Mountings not fitted with such supports need to be fitted with a steam coil of about six square feet surface area around the base of each mounting, as close as possible to the roller path. The coil must be screened from direct exposure to wind and spray.

b. *Electric Heating.* Two suitable switch sockets should be fitted in convenient positions on the mounting, or on the fixed structure nearby, for use with electric blankets or portable electric heaters. Electric breech heaters are also required.

705. NON-TRANSFERABLE MOUNTINGS

a. *Steam Heating.* Steam heating coils of appropriate surface area should be fitted as close as possible to roller pathways. Between-deck mountings, such as four point five or four inch mountings, require no special heating arrangements.

b. *Electric Heating.* Switches controlling sockets for muzzle heaters should be supplied for all mountings. If heaters are not



available, a string of 150-300 watt lights may be placed in the barrel, breech and near the recoil system to keep temperatures at reasonable levels. This must not be done, though, if ready-use ammunition is stored within the mounting.

706. FIRE CONTROL DIRECTORS

a. Where self-contained heating arrangements do not exist, a steam heating coil should be fitted inside the tubular supports of fire control directors, the surface area of which would be appropriate to a gun mounting with the same roller path diameter.

b. For simple tachymetric directors, suitable switch sockets should be fitted near each director for use with electric blankets and portable electric heaters.

707. RECOIL MECHANISMS

Recoil mechanisms containing a glycerine and water mixture will function satisfactorily in cold weather. However, sluggish action and a short recoil may become apparent at those temperatures below freezing when crystals form in the mixture, although the solution will not freeze until temperatures below the pour point are reached. Heat must be applied as soon as unsatisfactory recoil action is experienced. The orifices in recoil mechanisms are designed for a specific mixture of glycerine and water and no substitution is permitted.

708. AIRCRAFT GUNS

a. For reliable operation at low temperatures, guns must be clean and properly lubricated. When firing in sub-freezing temperatures, gun heaters are required and should always be turned on just before take-off.

b. Before firing, guns should be disassembled, cleaned, inspected for defects or part breakages, and lubricated. While disassembled, it should also be determined that all traces of hard drying preservatives have been removed from all working parts of the gun.

c. It is important that all springs be within their prescribed tolerances of free length.

d. All traces of solvent used in cleaning must be removed before reassembly. Incomplete removal of the bore cleaning solvent may result in malfunctioning at low temperatures. Immediately after cleaning, if guns are to be ready for firing, they should be lubricated with the prescribed lubricant. If guns are to be stored after cleaning, a suitable preservative must be applied.

e. Apply oil sparingly. Never dilute lubricating oils with kerosene. Cold temperature tests have shown that gun operation at low temperatures is not improved by diluting the lubricating oil in such a manner. Further, at temperatures warmer than −29°C, this mixture is not a satisfactory lubricant.

f. Guns rust rapidly from condensation when taken from the cold into a warm building. After reaching room temperature, they should be stripped, their parts wiped thoroughly dry and clean and immediately oiled. This procedure must be repeated every time guns are brought into a warm space from the cold outside.

g. After guns have been installed in an aircraft, and before flight, a careful inspection is recommended carefully observing the following safety precautions:

(1) Before working on the guns, remove the feed belt and feed mechanism, making sure no live rounds are in the chamber, or in the gun mechanism.

(2) Do not operate the charging mechanism or perform any

work on the hydraulic system while the feed mechanism and the ammunition belt are connected to the gun. After these components have been removed, check again that there is no round in the chamber.

(3) Do not operate gun switches, or make electrical tests, without first removing the feed mechanism and ammunition belt from the gun, and inspecting the chamber yet again to ensure that it is not loaded.

709. GUNSIGHTS AND AIRCRAFT FIRE CONTROL EQUIPMENT

All gunsights and aircraft fire control systems should be capable of operating at temperatures as low as −48°C, provided the correct lubricants are used.

710. BOMB SIGHTS AND BOMB DIRECTORS

Most bomb sights will perform satisfactorily at low temperatures. Some have proved to be satisfactory to −54°C while others, of a less elaborate type, will operate at temperatures to −40°C.

711. AMMUNITION

a. Ammunition must be kept in protected storage and at temperatures not below the minimum safe values prescribed for the explosives concerned. Propellants should be maintained at a temperature above −17.7°C. Rocket motors are subject to the same requirements as smoke-less powder cordite, as far as storage temperatures are concerned. Some rocket motors are susceptible to cracking if handled at low temperatures.

b. Safe firing temperatures for rocket and jet-assisted take-off (JATO) should be stencilled on the rocket motor or the JATO unit. These temperatures represent the minimum temperatures at which the rocket motor or JATO unit should be used and are not necessarily the ambient air temperature. If the temperature of the JATO unit has been permitted to drop below the prescribed minimum, it cannot be considered safe for firing at any temperature. All aircraft gun ammunition must be capable of firing to −54°C.

712. LUBRICANTS

a. Under Arctic conditions, certain lubricants prescribed for normal use tend to congeal and cause unsatisfactory operation. In general, lubricants approved for use in ordnance service should meet specification requirements at temperatures to −18°C. Changes in lubrication required for use in Arctic service include the dilution of high viscosity oils and heavy greases with low viscosity oils, or replacement with a suitable low temperature lubricant. Excessive amounts of lubrication must be avoided. Cold weather re-lubrication of ordnance should be completed before entry into low temperature areas, i.e., before temperatures drop to −18°C and below. However, if cold weather is encountered before re-lubrication has been completed, special methods for removing the congealed lubricant must be used.

b. When re-lubrication is required, accessible grease lubricated parts should be cleaned before applying the cold weather lubricant. Where parts are not accessible, it is recommended that the device concerned be operated while relubricating, care being taken to remove all excess grease.

c. When removing oil, it may be necessary to raise its temperature to ensure the job is properly completed. This may require operating the equipment for a period of time, then draining the oil and refilling with cold weather lubricant. Oil which becomes trapped in pockets should be removed with a suction pump. In the case of oil lubricated parts which do not depend upon a pump, but are lubricated by direct application, large quantities of cold weather lubricant must be injected to flush out the original lubricant.

713. TORPEDOES AND TORPEDO TUBES

a. In surface vessels, torpedoes are protected from cold weather by the torpedo tubes. Submarine torpedoes are protected by the normal ship environment.

b. In surface vessels, heaters (preferably electrical) are required for exposed torpedo tubes and muzzle door and training mechanisms, if fitted. Heating should be used at ambient temperatures below 5°C.

714. MINES

a. Because of chilling, mines are vulnerable to mechanical defects due to frosting or icing and the loss of potency of dry cell batteries. Naval mines are not required to function in ambient temperatures of less than −1°C. Since a mine will eventually assume the temperature of the water in which it is laid, and since neither icing nor loss of battery power are apt to cause permanent disablement of a mine, there are no special cold weather procedures for these weapons. However, in certain exceptional conditions, a mine may fail to be laid properly because of the effect of intense cold. An example of this would be heavy icing of the flight gear of an aircraft-carried mine, preventing the opening of its parachute.

b. Dry cell batteries used in underwater ordnance lose their potency or capacity at low temperatures. Few will operate at all when temperatures fall as low as 18°C. Others will become impotent at temperatures of 0°C. The controlling factor is shelf life, which appears to depend upon factors other than lapse of time alone, notably upon the degree of chemical action which occurs before placing the battery into service. Fortunately, the chilling of a dry cell to the point of loss of potency does not prevent recovery of potency when the cell is re-warmed except in unusual cases when the freezing of the electrolyte has caused mechanical damage to the cell itself. If dry cell batteries must operate between 0°C – 18°C they should be selected from a batch having the shortest shelf life and from those which have been continuously stowed in refrigeration, i.e., at 5°C. This is because refrigeration slows chemical action and lengthens shelf life.

715. MINESWEEPING GEAR

a. Magnetic minesweeping cable must be warmed by the best means available before being streamed, and the gear itself kept free of ice. Magnetic minesweeping operations in ice should be kept to a minimum and every care taken to prevent ice from cutting the sweep cable.

b. Motor-driven acoustic minesweeping gear requires heated inside stowage, when not in use. If this is impossible, the gear will have to be stowed on deck, under cover, with a portable heater. After streaming, the gear needs to be left in the water for two hours for temperature adjustment before operation.

c. Apply heat during and after recovery of cable to aid drying and reduce icing. Before streaming and recovery, remove ice on stern roller chocks and intermediate rollers so that rollers turn freely. During recovery, remove any ice on cable and dry as much as possible to prevent its freezing together when reeled.

716. MISSILES AND MISSILE SYSTEMS

a. Missile systems are designed with an all-weather capability, provided the recommended lubricants and fluid systems with heaters or anti-freeze are used.

b. Missiles are usually stored in a controlled environment until immediately before firing. In extremely cold weather, or under icing conditions, a missile should not stay on the launcher more than about two minutes. Should this time be exceeded, strike the round below and select another.

c. A de-icing system is required on the launcher and on the cell doors.

717. AHEAD-THROWING WEAPONS

a. *Hedgehog.* A self-draining steam coil should be fitted between the deck and the swinging beam with a minimum clearance of 2.25 in. being allowed for below the swinging beams. The shut-off valve in the stream supply and the drain tap should be fitted below decks for maximum protection. Canvas covers should also be supplied.

b. *Squid.* A self-draining steam coil of 0.75 in. bore should be fitted inside the base frame of the mounting. Framed canvas covers should be provided, part of the frame's cover being removed for loading and firing.

c. *Weapon Alfa.* Rockets are stored in a below-deck heated ready service ring. The launcher has electric heaters installed to maintain operational status.

CHAPTER 8

ELECTRONICS

801. GENERAL REQUIREMENTS

a. The following is an outline of some of the requirements for electronic equipment applicable to most types of ships:

(1) All exposed shipboard equipment should be capable of operating at temperatures down to −50°C.
(2) All exposed electronic equipment should be capable of withstanding wind velocities of 100 kt. at any temperature down to −50°C.
(3) All mechanically operated equipment must be lubricated with low temperature lubricant and adequate space heating fitted in spaces where this is feasible, e.g., inside radar pedestals.
(4) Electric heaters should be installed in inside covers of electronic equipment fitted on weather decks.
(5) Insulators should be lengthened approximately ten percent or the next higher voltage rating over the normal standard as extra protection against shorting caused by ice formation.
(6) Antennae to be designed to withstand an ice load, two inches thick, around the component parts of each antenna. The diameter of wire rope antennae should not be less than 0.38 in. All whip antennae to be capable of withstanding wind velocities of 100 kt. when coated with ice two inches thick.
(7) Cables and cords to be handled with care to prevent fracture. The flexing capabilities of each particular cord must be studied, and it should be handled accordingly. At extremely low temperatures, cables should be unreeled in a warm space before use.

802. EXPOSED ELECTRONIC EQUIPMENT

a. With the foregoing requirements in mind, all equipment should be appropriately winterized and preheaters used wherever possible. The practice of lengthy warm-up periods under no-load or light-load conditions is also recommended.

b. Equipment that is not in regular use needs to be heated periodically to drive out moisture. Wave guides and other non-pressurized lines in which condensation accumulates should be fitted with drain cocks and be drained at regular intervals. Planned maintenance schedules for ships should include this as a periodic check. Wave guide dryers, if provided, must be used as directed.

c. Equipment which is used in exposed positions, and which is returned to warm spaces for stowage after use, must be thoroughly dried out to remove all traces of moisture formed by condensation due to temperature change. After drying, the equipment should be left open in the warm space for some time prior to stowage.

803. ICE ON ANTENNAE

Ice formation can be a hazard on all types of external antennae, causing breakage or changing antenna characteristics and reducing operating range. Ice which has formed should be knocked off with a thin pole. Ice and snow should also be removed from strain insulators to prevent excessive transmission losses. Wire antennae need to be kept a little loose, as a slight whip will crack the ice.

804. VARIABLE SPEED ANTENNAE

Variable speed antennae should be operated at low speed for a short period before increasing rotation speed. Direction of rotation must not be changed, nor antenna rotation accelerated or decelerated rapidly, *until gear trains and drive motors are thoroughly warmed up*. Installation of electric heaters in antenna pedestals is recommended.

805. SLOW-MOVING MECHANICAL PARTS

Slow-moving mechanical parts, such as shafts and bearing surfaces, will operate more satisfactorily if the surfaces are buffed and polished. Such surfaces should not be lubricated unless this is essential, and even then it should be done sparingly.

806. COVERED CABLES

a. Rubber-covered, flexible cable becomes stiff at temperatures lower than −6°C, the insulation becomes brittle and is liable to crack and shatter rather than bend. Accordingly, sharp bends in cables should be avoided.

b. Synthetic materials (e.g., polyethylene) are replacing rubber for insulating purposes, and they have much improved cold weather characteristics.

807. ELECTRIC INSTALLATIONS

a. Electronic installations should be made with special care to minimize the effect of cold, moisture, high humidity and stresses due to icing as follows:

(1) Wire size of radio antennae to be increased to compensate for high winds and ice loading of long horizontal spans. Receiving antennae using small size wire are vulnerable to damage by ice loading.

(2) Install double antenna suspension insulators for transmitting antennae to increase leakage path and to prevent arc-over.

(3) Oil in the pedestals of rotating radar antennae should be replaced with oil that will not congeal at low temperatures. Consideration should be given to the installation of oil heaters.

(4) The radar antenna pedestal heater should be connected to a circuit that will remain energized when the radar set itself is disconnected.

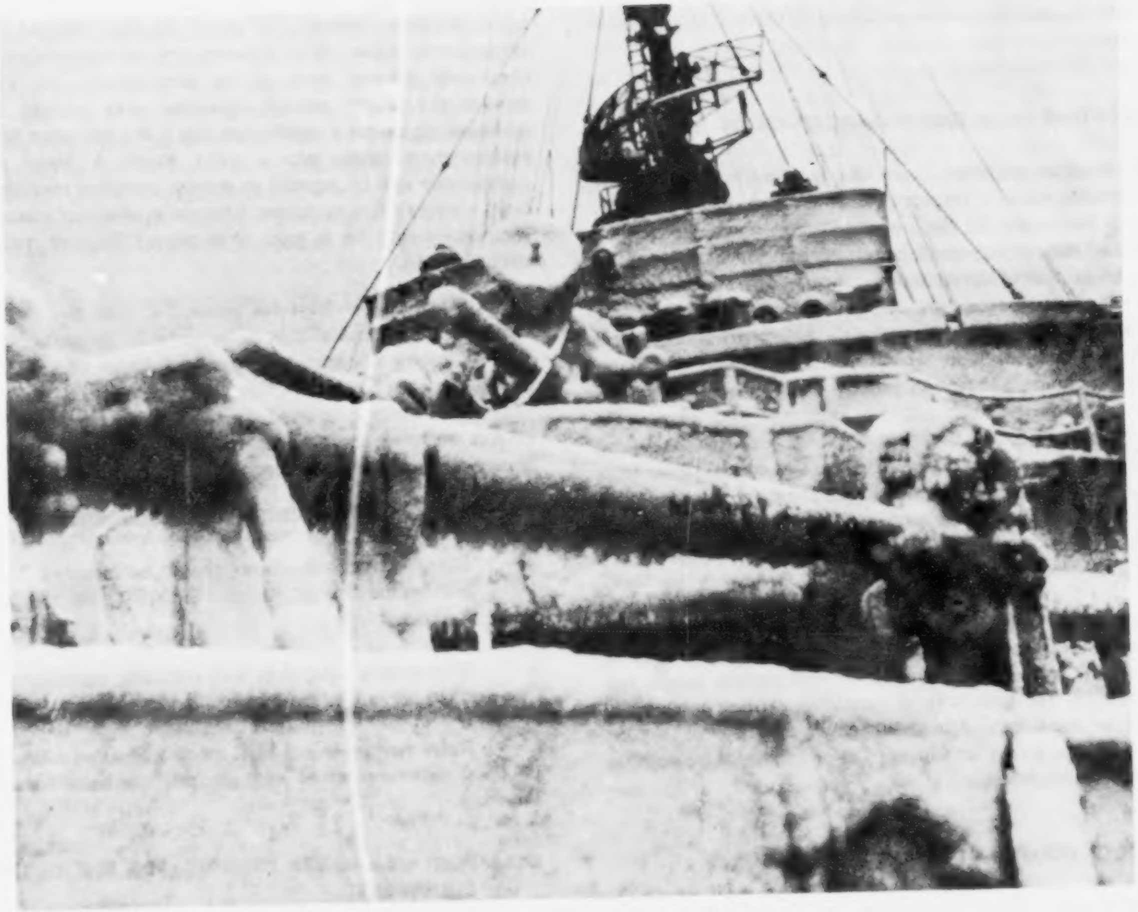
(5) Mounting brackets and foundations of equipments should be oversize in ships which may become involved in icebreaking operations.

808. TELEPHONES AND MICROPHONES

In using telephones or microphones in exposed locations, care should be taken to prevent the speaker's breath from freezing the microphone. In general, the use of portable microphones supplied with a transmitter station which is in a protected space is preferable to those located in the open.

809. COMMUNICATIONS EQUIPMENT

Communications equipment for high latitude operation should include a transmitter with a high frequency operating range of at least 26MHz, and another which will operate on frequencies as low as 175 – 195 kHz. Both of these transmitters must have substantial power capabilities. All transmitters and receivers should be calibrated on the several frequencies expected to be used. To capitalize on the advantages of low frequency operation and very low frequency reception during



blackout periods, antenna systems additional to those already installed may be required.

810. EFFECTIVE RADIATION CHARACTERISTICS

a. The standard shipboard transmitter required for high latitude operations usually covers a frequency range down to 175 – 195 kHz, depending on the model. At the lower end of the range, the radiated power obtained may be very small, being something of the order of 0.6 percent to 1.5 percent of the rated output power. This is caused by the inability to load the antenna properly because of its short effective length. Radiation is further decreased by the necessarily short vertical section of the antenna upon which radiation depends. Optimum radiation with current shipboard antennae is usually realized at around 500 kHz and effective radiation decreases as the operating frequency is decreased. It has been found, too, that in operating the low frequency transmitter at frequencies in its lower range at substantial power (one or two kw) using standard shipboard antenna, severe arc-overs and large losses in antenna trunks will be experienced due to high standing wave ratios, with high voltage occurring at the insulators caused by inadequate effective lengths.

b. For these important lower frequencies to be used during periods of ionospheric disturbances, arrangements may have to be made to install temporary transmitting antennae of the greatest length and height practicable. The possibility of paralleling existing antennae in series might be considered, nor should emergency use of balloon suspension be overlooked. (See Chapter 16 for additional information on high latitude communications.)

811. CARE OF EQUIPMENT IN LOW TEMPERATURES

a. In most cases, special precautions may be required to ensure satisfactory operation at temperatures lower than −2°C.

b. Airborne electronic equipment has been designed to operate at temperatures below −48°C. However, dry cell batteries and electrolytic condensers will not work at low temperatures, but will probably recover and resume normal operation when warmed. Here again, condensation can be a problem because it will take place whenever cold equipment is taken into a warm room. A higher standard of maintenance will be required to prevent corrosion resulting from such rapid changes of temperature. Changes in electrical characteristics of components may be so great as to require frequent readjustment of critical circuits.

c. When temperatures fall below 2°C, heat should be applied to electronic equipment if it is to be ready for immediate use. Batteries and electrolytic condensers, in particular, must be kept warm if they are to operate efficiently. Continuous operation in the "standby" or "filament" position is good practice as it keeps equipment at the correct operating temperature before plate voltage is applied, and it eliminates condensation inside the equipment.

812. UNDERWATER ELECTRONIC EQUIPMENT

a. Echo sounder transducers should be mounted flush with the hull to prevent ice damage. Recesses in the hull will trap ice and cause faulty operation.

b. Echo-ranging equipment with retracting transducers requires an "ice-gate" to prevent entry of ice into the transducer sea chest.

c. Radar waveguide and ECM antenna masts on submarines should be filled with pressurized nitrogen and the heaters energized continuously.

813. PORTABLE POWER SOURCES (FOR ELECTRONIC EQUIPMENT)

a. Portable internal combustion power generating equipment should include a small aerosol type can of ether, which is obtainable from shipboard medical detachment, to facilitate cold weather starting. Extreme caution should be exercised to limit the quantity injected into either gas engine carburetor or diesel engine air intake. Do not allow contact with exposed body areas, as frost bite would be extremely likely. If these equipments are to be shut down or left turned off for extended periods, the lube oil should be drained while engine is hot and stored inside the ship or personnel shelter, along with the starting batteries if so equipped. Often it is more advantageous to leave engine starting batteries inside and extend cables outside to the generator.

b. Small low power communication transceivers should be kept inside the clothing to allow body heat to extend battery life. This includes spare battery packs as well.

814. MAINTENANCE (PERSONNEL PRECAUTIONS)

a. Prior to attempting any maintenance aloft, all primary and radiated power on the affected systems must be secured and tagged to this effect. This applies to all adjacent radiating antennae also.

b. No maintenance aloft should be attempted unless an emergency condition exists, and then only *after* the rigging of an appropriate canvas wind screen protective cover against wind chill and the installation of portable heaters inside to allow maintenance personnel an opportunity to remove gloves, masks and attach safety harness, prior to attempting any electronic type rapairs. (Solder will not flow at −20°C using conventional irons.) Replace gloves prior to leaving the shelter, to keep hands from freezing to ladder rungs or hand rails; do this regardless of how short the anticipated time of exposure may be.

c. Two safety belts must be worn when working aloft, one of which must be secured firmly at all times. Positive footing is *never* available aloft in northern waters and becomes more pronounced when personnel are required to wear cumbersome clothing and footwear

d. The installation of communication whip antennae in the vicinity of smokestacks or boiler room uptakes usually prevents the formation of ice. However, periodic cleaning is necessary to remove soot accumulations and prevent degradation of antenna performance. The cleaning aspect does not present a problem when the whips are of the retractable type and access to the top of the stack is gained through an internal trunk and scuttle arrangement. Breathing masks and safety belts must be worn at all times to prevent smoke and stack gas inhalation and to conform to "safe working practice aloft" criteria.

CHAPTER 9

PERSONNEL

901. INTRODUCTION

a. The success of any Arctic operation will ultimately depend upon the effectiveness of the officers and men involved, who must be in good health, physically fit and mentally alert. All concerned should have the mental flexibility to endure with cheerfulness long periods of boredom, drudgery and hardship.

b. The principles of preventive medicine apply with as much force in Arctic service as elsewhere. There should be little difficulty dealing with those whose activities will be confined largely to the relatively sedentary life onboard ship. However, for those contemplating extensive shore duty in remote areas, where the demands on men will be much more arduous, a different set of rules apply.

902. TRAINING

a. Nowadays, for most officers and men serving in ships, there is little to be said on the subject of special training for Arctic operations. Any well indoctrinated ship's company should easily adapt to these conditions, just as they would for any other part of the globe.

b. In high latitudes in the summer there are twenty-four hours of daylight. This sometimes causes a problem until personnel accustom themselves to this strange phenomenon. On the one hand there is a tendency for a few diligent souls to continue the habit of working through most of the daylight hours, inevitably a short lived and exhausting experiment. On the other hand, however, it generally takes a good deal more than non-stop daylight to prevent a sailor from getting his sleep.

c. If a ship should be compelled to winter-in, then her people would have to adapt themselves to a new set of living and working conditions, including the prospect of twenty-four hours of darkness. But such a prospect should not be too daunting. Wintering-in has been successfully accomplished before by men in very much less favourable circumstances.

d. Those undertaking an Arctic operation, particularly one of a prolonged nature, should recognize the need for self-discipline. This is a matter of attitudes in the minds of people and cannot be taught in a classroom. There are few ports of call, mail deliveries will be infrequent and uncertain, and boredom will probably become a major problem. There is, however, much to do and learn in this unusual environment.

903. FOOD

a. Provisioning and menu planning should be arranged to provide a diet high in caloric content. The following table suggests daily requirements of nutritional elements which ought to be provided for each man:

Calories	3,000–5,000 (depending on activity and exposure to cold)
Protein	55 gm
Calcium	5 gm
Iron	6 gm
Vitamin A	2,700 IU
Ascorbic Acid	30 mg
Thiamine	1.38 mg
Riboflavin	2.3 mg
Niacin	13.8 mg

b. Food is particularly important in providing relief from monotony and for this reason menus should be as varied and appetizing as possible. There is a tendency on the part of some to overeat, but this is not a serious problem. There are some special requirements for officers and men who may disembark for shore duty in the Arctic, particularly an increased need for fat and vitamins. The "Polar Manual" by Captain Hedblom, U.S. Naval Medical School, is recommended for the wealth of information it contains on health and diet, among other matters, in the polar regions.

c. Weather deck stowage of fresh food is, of course, out of the question in the Arctic. Auxiliary refrigeration may have to be provided to accommodate fresh vegetables in ships where the usual stowage of such items is outside. Inside stowage of provisions against an uninsulated hull should be avoided as low temperatures will cause condensation resulting in mould damage.

d. If the galley staff is small, provisioning should include convenience foods which will reduce the need for labour and preparation time, yet maintain menu variety. It is suggested that one galley, or part of one, operate on a twenty-four hour basis to provide for watchkeepers, boat's crews and parties of men going to, and returning from, shore duty.

904. FRESH WATER

Although individual tastes vary with regard to salt, water which has a salt content of one or two parts per thousand will often be chosen in preference to distilled water. A salt content as high as ten parts per thousand can be tolerated in emergencies without harmful effects and such water can be used freely for cooking. The boiler water kits carried by most ships may be used for water analysis.

905. CLOTHING

a. The first requirement is to keep warm without perspiring. If overheating does occur, it should be possible to shed clothing readily so that perspiration cannot accumulate. Clothing based on that principle is now readily available and consists of various garments designed to trap air in layers without being uncomfortably bulky. It must never be tight and outer layers must be windproof.

b. It must be possible to manipulate fastenings while wearing gloves or mitts and these, as well as headgear and footwear, should be of special design and proven material. In conditions of extreme cold it may be necessary to provide face masks. Anti-glare goggles or sun glasses are required as a precaution against snow-blindness. Men who require eyeglasses should be provided with a spare pair and should be issued with sun glasses, of an approved design, ground to their prescription.

c. For operations ashore provision must, of course, be made for certain essential needs – shelter (tents or snow shelters), food and drink, first aid, cooking and heating equipment, sleeping bags and a reliable means of transport and communication.

906. SHIP HABITABILITY

a. Modern ships, with their air-conditioning systems, generously stocked provision rooms, laundries and recreational facilities, are so well equipped and self-contained that their crews should have much to be thankful for.

b. Apart from the possibility of boredom for some, modern sailors travel in a most comfortable environment and suffer few inconveniences, let alone so-called hardships. Indeed, men in certain trades, whose duties rarely require them to appear on the upper deck, could complete an Arctic voyage without really being aware of it. In contrast to the Arctic explorers of old, there is virtually nothing in the way of habitability requirements demanding special attention just because a ship is about to embark on an Arctic operation.

907. DISEASE PREVENTION

a. Medical problems grow in proportion to the distance from the nearest medical help. Understandably so. Those problems which would otherwise be relatively unimportant, may instead appear to be critically important when they occur in a ship lacking a qualified medical attendant.

b. For Arctic service it is desirable to carry a medical officer. Failing this there should be someone on board who can examine a patient, give a factual report by radio, and be capable of carrying out a doctor's instructions and be equipped to do so.

c. Every effort should be made to eliminate those who are known to have medical or psychological problems, or who have any record of illness on previous Arctic service.

d. If crew members have recently been brought together, a mild "epidemic" of upper respiratory infection is likely. Men so affected should be given light duty for a few days in a stable environment.

908. MENTAL HEALTH

a. Boredom can become a problem, leading in some cases to serious mental depression. When a man has been an active member of a group but withdraws from its activities, or becomes uncommunicative, there is a strong possibility that he is in need of medical help.

b. Mental depression can usually be kept at bay by providing a full range of individual and group activities. Idleness breeds discontent and nowhere is this more true than in a ship engaged on extended Arctic service. All the standard amenities should be provided in abundance – movies, books, hobbies and handicrafts. Group activities should also be encouraged.

909. MEDICAL – GENERAL

Frostbite, immersion foot, hypothermia and snow blindness are four hazards associated with Arctic service which can, in most instances, be avoided if care is exercised. (See also Chapter 17, Articles 1712 and 1713.)

910. FROSTBITE

a. In this condition exposed tissue actually becomes frozen. The cheeks and nose most frequently fall victim to frostbite but, due to their good circulation, lasting damage is unlikely.

b. Fingers are vulnerable if, to improve dexterity, they are exposed or if gloves or mitts become mislaid. The intense pain from a cold hand usually results in action to warm it to forestall further freezing.

c. Feet, unfortunately, are not as accessible as hands for warming and they may have to be neglected despite the warning pain, resulting in frostbite there with greater frequency than is the case with the hands and face.

d. In the first-aid treatment of frostbite, nothing should be done which could further injure the frozen part. No rubbing, no pressure from dressings, and no ointment can be permitted. The injured person should be taken into a shelter where rapid rewarming can be undertaken.

e. Superficial frostbite can be treated by warming the affected area with another part of the body – as for example a hand over a frozen cheek, or frozen fingertips placed in an armpit.

f. In cases of severe frostbite, treatment is by immediate thawing, immersing the frozen part in hot water (40°C – 42°C) which is bearable to the elbow, until the distal parts once more become pinkish. The water should be in motion, preferably in a whirlpool bath. Pain relieving drugs may be necessary at this stage.

g. Further treatment after thawing consists of the affected part being left exposed, protected from the weight of blankets by some sort of support, and from further exposure to cold. The frost-bitten part should be cleansed gently each day with hexachlorophene, or mild soap or detergent, and warm water in a bath. Any blisters which form should be left intact. Use pledgets of cotton to separate affected digits and administer tetanus antitoxin. At the first sign of cellutitis, antibiotics should be given.

h. While there is no reason why alcohol should not be administered, its beneficial effect as a vasodilator in the treatment of frostbite is unproven. There is also no conclusive evidence that vasodilator drugs are of value in the treatment of frostbite.

i. Active joint motion of the affected extremity must be encouraged, particularly while in the daily bath. If the lower extremity is involved, the alternate raising and lowering of the leg over the bedside, three to six times, accompanied by ankle and toe movement, is beneficial in stimulating circulation. This treatment should be undertaken three times a day.

j. No surgical intervention should be attempted until there is a clear line of demarcation between the gangrenous and healthy areas, which may take from four to eight weeks.

k. Prevention is the best treatment for frostbite. With this in mind it must be realized that wind chill (i.e., the combined cooling effect of wind and low temperature), the duration of exposure and the adequacy of clothing are important factors. Frostbite can occur very rapidly when facing a strong wind in low temperatures without face protection. Men should be instructed to inspect each other's faces frequently for signs of frostbite, which will be indicated by areas of skin turning white. The incidence of frostbite is rare among Arctic-indoctrinated and self-disciplined men.

l. Spilled fuel on the skin can result in quick freezing and severe frostbite of the affected area.

911. IMMERSION FOOT

a. This condition occurs as a result of prolonged wet cooling of the feet and legs at temperatures above freezing, particularly when the legs are dependent, circulation is restricted, and the legs and feet are relatively immobile. Men adrift in rafts and boats would be vulnerable to immersion foot.

b. In the early stages, when the blood circulation is reduced, the foot becomes swollen, cold, waxy and mottled. There are cyanotic blotches and the foot is numb. This condition is followed by increased circulation which may continue for weeks. The foot then becomes red, swollen and hot. Blisters often form and pain may be intense.

c. Immersion foot is a serious condition which can result in gangrene or prolonged disability. It requires expert medical care and patients so affected should receive treatment as soon as possible.

d. First-aid treatment consists of removing the patient from the wet cold environment, taking off boots and socks and elevating the extremity. The foot should not be warmed, either in a bath or artificially. It must be protected from injury, blisters should be left intact and no rubbing or massage permitted.

e. The importance of preventing immersion foot is obvious. Do not allow the legs to remain immersed or wet for any length of time, avoid constrictive footwear and keep exercising the legs and feet.

912. HYPOTHERMIA

a. In this condition the body temperature falls as the body's

capacity to generate heat can no longer keep pace with the rate of body heat loss. This usually occurs in persons suffering from exposure. Such persons are either without proper clothing, or have been injured or fatigued to the stage of immobility. Immersion in cold water also results in hypothermia.

b. The onset of this condition is insidious. An individual complains of feeling cold, becomes listless, tired, and wants to lie down and rest. If he surrenders to this urge, hypothermia progresses rapidly. Irrational behaviour is a serious sign and is often followed by unconsciousness.

c. Treatment depends upon the severity of the condition. In the early stages it is sufficient to get the person into shelter and to warm him by any means available. Wet clothes, of course, must be removed.

d. In severe cases, in which collapse has occurred or is imminent, vigorous treatment is required. Ideally the patient should be immersed in a hot bath (42°C – 44°C) until body temperatures become nearly normal. Failing the availability of a bath, vigorous methods of rewarming by any means must be undertaken. Remove wet clothing and place the patient in a sleeping bag or blanket. Use hot water bottles taking care not to burn the patient and, if he is conscious, administer hot food and drink.

e. If rewarming has not been rapid, acute heart failure or cardiac arrest may occur, calling for immediate cardiac massage. Mouth to mouth artificial respiration may also be required.

f. Prevention is the ideal state of affairs and should not be too difficult. Leaders must insist on adequate dry clothing, ample nutrition, the avoidance of fatigue, and be on the lookout for the early signs of hypothermia. Incipient cases should not be permitted to lapse into inactivity. There is always the possibility of hypothermia whenever a person is forced into inactivity in the cold or as a result of injury.

913. SNOWBLINDNESS

a. This is caused by the sensitivity of the eye to ultra-violet radiation. The Arctic sun is never high above the horizon and its effect is intensified by reflection from snow and ice so that considerable ultra-violet light can fall onto the retina.

b. Early symptoms are a scratching sensation under the eyelids and a deep pain in the eye. These may progress to intense pain, aggravated by light, so that it becomes impossible to open the eye. The white of the eye becomes reddened.

c. Treatment consists of keeping the eyes bandaged and the patient in darkness until the reaction has subsided. Pain relieving drugs, such as butyn drops or ointment plus sedatives, will be required. Cocaine eyedrops should not be used because of their softening effect on the membrane covering the eye.

CHAPTER 10

GENERAL OPERATIONS

1001. INTRODUCTION

a. The vehicle which is built to operate within ice-covered waters is the icebreaker. Because of its special features it is the backbone of most large scale Polar operations.

b. During construction of the Distant Early Warning Line in the Canadian-Alaskan Arctic in the late nineteen fifties, cargo carrying ships demonstrated, in impressive fashion, an ability to penetrate ice-covered waters which hitherto had been thought impenetrable to non ice-strengthened ships. Until a better means of moving cargo is developed, cargo vessels will continue to be the most reliable and economical carriers and, because of this, there will continue to be a requirement for icebreakers to escort them.

1002. ICEBREAKERS

a. Broadly speaking there are three categories of icebreakers:

(1) Harbour.
(2) Non-Polar.
(3) Polar.

b. Type (1) covers small icebreaking vessels, generally not much larger than tugs, engaged in keeping rivers and small harbours clear of thin ice. Type (2) embraces large icebreakers employed in keeping areas of sea clear of ice, freeing ships trapped in areas such as the Baltic and the Gulf of St. Lawrence. Type (3) covers icebreakers capable of operating in very heavy and hard Arctic ice. In addition, ships of this last type usually support oceanographic, hydrographic and other related scientific activities in the Polar regions. The remarks which follow apply, in the main, to Polar icebreakers.

c. To make them more manoeuvrable, icebreakers are usually equipped with some form of high speed steering control to enable them to avoid heavy ice floes in their path. This feature is in addition to the more conventional steering arrangements. Rudders and associated fittings must be very ruggedly built to withstand heavy shocks, particularly when working astern in ice.

d. To exploit the tremendous versatility and usefulness of the helicopter, icebreakers are now invariably built with hangars and flight decks from which such machines can operate. Because flying conditions in the Arctic are so unpredictable, facilities should be built into the parent ship providing her with positive control over her own helicopters. This means that efficient air surveillance and tracking radars must be installed together with good plotting and communications facilities.

e. Should an icebreaker become stuck in the ice, and her engines cannot free her, heeling and trimming tanks are provided, together with large capacity transfer pumps. Sea water, or fuel, can be transferred from one side to the other in large quantities and very quickly – 275 tons in 90 seconds is an example of a typical system. Similarly, liquid can be moved from a forward trimming tank to an after one, or vice versa, though at slower rates. These activities, when used in conjunction with the ship's engines, are usually sufficient to start the ship moving.

f. With regard to draught, it should be sufficient to accommodate large propellers whose tips, when in the upper position, will be at least seven feet below the surface of the water.

g. The true test of an icebreaker is her ability to break ice, and two factors which influence this are weight (displacement) and the power to use that weight. It is for this reason that icebreakers are designed on a horsepower/displacement basis. Generally speaking, for Polar icebreakers, the horsepower per ton of displacement lies in the region of 1.80 – 2.90.

h. There are five factors which govern the ability of a Polar icebreaker to do the job she was designed to do, and do it effectively. These are:

(1) The power, displacement and strength of the ship.
(2) The nature and extent of the ice being attacked.
(3) The shape of the hull, particularly the bow form.
(4) The capability of rapid heeling and trimming.
(5) The skill, experience and intelligence of the man handling the ship.

1003. TYPICAL MODERN POLAR ICEBREAKER

a. One of the latest Polar icebreakers to be built is the Canadian Coastguard's Louis S. St. Laurent which is to be assigned to Arctic patrol service, particularly in the eastern Arctic waters of Canada.

b. Each new Polar icebreaker is bigger, stronger and more powerful than her immediate predecessor and the Louis S. St. Laurent is no exception. She is 367 ft. overall, with a beam of 80 ft. and a draft of 31 ft. Propulsion is steam turbo-electric driving three propellers with a total shaft horsepower of 24,000 giving a maximum speed of nearly 18 kt., a cruising speed of 13 kt. and a range of 32,000 miles.

c. Flume type stabilization is fitted to reduce rolling in heavy seas when on passage to, or returning from, her operating area. A novel feature is the installation of a water-jet system (bow thruster) to assist in manoeuvring, especially when working through and around heavy ice. Heeling tanks and high capacity pumps are included, together with a fully automatic cycling system, to provide high speed heeling, which can be invaluable when moving in ice.

d. Additional features include a hangar, lift and flight deck for two helicopters. A constant-tension towing winch is installed aft, enabling her to tow ships of any size should this become necessary. Two 50 ft. landing craft are carried to permit over-the-beach landing of cargo – these boats are in addition to the usual complement of smaller work boats. Cranes are provided to handle cargo, boats, aircraft and also to hoist out and launch the large number of inflatable life-rafts carried.

e. Ample facilities for oceanography and hydrography are provided. Altogether accommodation is available for 216 officers, scientific personnel and crew members.

f. A well equipped crowsnest is provided from which it is possible to control the ship and her engines. However, experienced icebreaker captains prefer to use their bridges and to rely instead on the valuable information supplied to them by their own helicopters and ice observers.

1004. SHIPS

a. It has already been pointed out that well-found cargo ships, though not designed or strengthened for ice navigation, can operate successfully in moderately severe ice conditions in the Arctic without suffering serious damage. The likelihood of such ships emerging unscathed will be even further improved if they invariably co-operate wholeheartedly with escorting icebreakers and follow routing advice when acting independently.

b. Experience has shown that ship masters who are unfamiliar with ice navigation soon gain confidence when they understand some of the techniques peculiar to ice navigation. Caution is necessary at the outset and masters are always encouraged to seek advice. (See Chapter 11 – Ship-handling in Ice and Ice Seamanship.)

c. Only ships of the most reliable type should enter ice-congested waters. They must be fully powered, preferably ice-strengthened and with an excellent capacity and responsiveness for going astern when required. Confidently handled by competent officers, such ships are often able to proceed through ice without any assistance other than routing advice.

d. However, low powered non ice-strengthened ships of ordinary construction often become beset as soon as they enter waters that are relatively lightly ice covered. Such ships make continuous and often unreasonable demands for icebreaker assistance.

e. As a general rule, a full powered ice-strengthened ship should be able to make relatively good progress through five-eights winter ice. A careful assessment should be made of every aspect of wind and current in relation to ice drift when a ship is moving alone through waters where pack ice extends over large areas. Every effort should be made to avoid being caught between an extensive area of pack ice and the shore, or between the pack and a danger such as a shoaling area, when the wind is blowing strongly onshore. A ship that becomes beset is powerless to go anywhere but in the direction of the ice drift and probably into serious trouble.

f. The size of ships has an important bearing on their ability to navigate safely and effectively in ice. Large tankers and ore carriers (150,000 tons and up) when deeply laden may prove to be so effective in ice, when compared to smaller ships (5,000 to 10,000 tons) that they will become their own icebreakers. The tremendous momentum of such ships could be both good and bad: good in that they will be able to force a passage through certain types of ice; bad in that heavy ice which should be avoided might have to be struck because such ships simply cannot check their headway.

g. Such huge ships in certain circumstances, simply could not stop in time to avoid blundering into impassable ice ahead of them or possibly from ramming their escorting icebreaker from behind should the latter become stuck in a heavy floe. The fitting of bow thrusters would seem to be desirable to provide a measure of manoeuvrability such as is enjoyed by smaller and handier ships.

h. Captains of icebreakers will undoubtedly insist on much greater separation between their own ships and very large ships over 50,000 tons which they may be called upon to escort. This requirement could, in effect, undo much of the good achieved by the icebreaker because ice will drift back into her wake to obstruct a ship coming up astern.

i. The possibility of very large ships venturing into Arctic waters and requiring ice escort poses another problem because such ships have a beam of 120 ft. or more. The most modern icebreaker, however, does not exceed 90 ft. in width – the Louis St. Laurent, for example, has a beam of 80 ft. A path cleared through fast ice or heavy pack will, therefore, be narrower than that required by a large ship. Icebreakers may be compelled to work in pairs to clear a path of sufficient width or, if there is but one icebreaker, it may be necessary for her to proceed ahead to clear a path, returning to escort her charge through while at the same time widening her original track by making a second cut at the ice.

1005. SUBMARINES

a. The proposal to venture under Arctic ice by submarine is not new. Sir Hubert Wilkins advocated it in 1931 but he was ahead of his time for it was not until the successful development of nuclear propulsion, enabling submarines to remain submerged indefinitely, that such a scheme became practicable. In more recent years the impressive achievements of the United States nuclear-powered submarines in Arctic waters is proof that true under-ice navigation is here at last.

b. But despite these achievements, all is not plain sailing for submarines in the Arctic. In some areas, the depth of the water provides insufficient manoeuvring room between the ice canopy overhead and the sea bottom. In others, icebergs constitute a hazard to submarines proceeding at depths down to 500 ft.

c. Icebergs come in an infinite array of shapes and sizes. Those with blocky precipitous sides, whose proportions (exposed to submerged) are 1:5, extend the furthest into the depths. Large specimens encountered in Baffin Bay tower 300 ft. or more out of the sea and therefore must swim very deep in the water. Bergs found in the eastern Canadian Arctic come principally from the glaciers of Greenland. The twelve most important glaciers there are estimated to discharge 5,400 bergs annually. The Melville Bay region is also a particularly rich source of bergs and the iceberg traffic in Baffin Bay and Davis Strait is therefore very heavy. Much of this traffic finds its way further south to the Labrador Sea and beyond where eventually the relatively warmer waters there take their toll. Some also find their way to Lancaster Sound and Hudson Strait. Submarines operating in these, and other, areas frequented by bergs would be advised to proceed with caution.

d. To move large quantities of crude oil or iron ore from the Arctic to world markets, consideration has been given to the use of large nuclear-powered submarines. For example, one such vessel would have a submerged displacement of 50,000 tons enabling her to carry 30,000 tons of heavy density cargo. Her length overall would be 610 ft., hull diameter 70 ft. and her loaded draft 60 ft. when on the surface. Propulsion machinery, developing 50,000 shaft horsepower, would drive this underwater giant at 25 kt. by means of a single propeller of 25 ft. diameter.

e. While such a vessel would carry considerably less cargo than is possible even today in giant ships displacing 290,000 tons (with 500,000 tonners in the design stage and 800,000 tonners already contemplated), it does mean that a very substantial increase in lift capability could be made available in those areas which are now closed to virtually all surface ships for a long period every year. The major limiting factor would be shoal water areas. Such a capability could have considerable significance for future military operations in the Arctic.

f. For warlike purposes, a submarine represents a very effective vessel for deployment in ice-clogged waters. With the restrictions imposed on her by ice, a surface warship would be in perpetual jeopardy.

1006. AIR-CUSHION VEHICLES

a. In recent years air-cushion vehicles have demonstrated a capability in the Arctic which shows promise that such vehicles could provide an effective solution to some of the problems of over-ice transport.

b. In an area where the expense of building and maintaining year-round roads is out of the question, and where frozen channels deny access to most ships for a major part of each year, there is a requirement for an alternative means of transport.

c. Air-cushion vehicles appear to have an ability to operate over Arctic terrain and do it more economically than aircraft. In certain circumstances they could prove suitable carriers during the preliminary stages of development before it was practical to build roads; they might also be able to travel through the frozen channels of the Arctic archipelagoes.

d. Air-cushion vehicles possess certain advantages. In case of engine failure they are safer than a light aircraft or helicopter. The reservoir of air holding the craft up leaks away comparatively slowly enabling it to settle onto the surface and come to rest. Secondly it can float on water. Emergency stops can also be made on snow from speeds of 30 miles an hour without suffering damage.

e. If an air-cushion vehicle is sufficiently large, it can be designed to be more economical of power – and hence fuel – than an aircraft of similar capacity.

f. Air-cushion vehicles have the following basic features:

(1) They are capable of traversing a wide variety of terrain at speeds up to 60 kt. or more. In addition to travelling over water, land and ice, air-cushion vehicles can negotiate muskeg, soft snow and mixtures of thin ice and open water with equal facility. By their nature they are best suited to lands of gentle relief. Present designs can pass over irregularities (rocks, ridges of ice, etc.) up to 4 ft. high.

(2) They offer the conventional advantages of surface vehicles over aircraft: greater safety and, in the larger sizes, more economical operation.

(3) With present designs there is a certain lack of manoeuvrability and this, coupled with the fact that slow speed operation leads to increased fuel consumption, could be of concern in certain situations.

(4) Operation over water at temperatures below the freezing point could lead to spray freezing onto the craft and loading it down with ice.

1007. DIVING

a. *Diving Conditions.* The water is, of course, cold, the visibility excellent, and the bottom is generally flat. Shifting ice, driven by wind and current, is the greatest danger to divers. Most diving work is carried out in shallow water, clearing beach obstructions and surveying approaches to landing sites.

b. *Equipment.* A wet suit with compressed air breathing apparatus, both of which are easily transported and self sufficient, are suited to diving requirements in the Arctic. An air compressor is necessary for charging bottles and an inflatable rubber boat or raft, equipped with a small outboard motor, is handy and safe for transporting divers and their equipment.

c. *Explosives.* Explosives used in demolition of ice and rocks must have very high shattering properties. A variety of commercial explosives are available which meet this requirement. Ice is extremely hard to dispose of due to its density, and large charges are often necessary. A 60/40 ratio of Forcite and Nitrone has proved to be effective.

d. *Ship Repair.* This is occasionally necessary. Holes may be ripped in ship's plating, rivets may pop, propellers and rudders may need attention. Underwater cutting and welding equipment should be carried to facilitate such work.

CHAPTER 11

SHIP-HANDLING IN ICE AND ICE SEAMANSHIP

1101. INTRODUCTION

a. Successful penetration of an ice-filled sea calls for knowledge and experience of conditions peculiar to the Polar regions. For those to whom this specialized activity is unfamiliar, the only way to prepare for it is by studying the accumulated knowledge of those who have gone before – of which there is a great deal. Then simply learn by doing.

b. The inexperienced navigator and ship-handler in ice in the Arctic is advised to develop a healthy respect for the latent power and strength of ice in all its forms. The peaceful appearance of an ice field should never lull him into a false sense of security. However, progress can usually be made through ice, or (better still) around it, by a ship in capable hands.

c. The first principle of ice seamanship is to maintain freedom of manoeuvre in the presence of ice. As long as a ship remains free, she can go where the breaks occur. Should she become trapped, however, she would have little choice but to go where the ice goes.

d. Three thoughts should be uppermost in the mind of a commanding officer whose ship is working in ice:

(1) Keep the ship moving – even slowly.
(2) Try to work with, not against, the ice.
(3) Be infinitely patient. The longest way round can often be the quickest, and also the safest, way home. Ice is no respecter of schedules.

1102. NON ICE-STRENGTHENED SHIPS

a. Ice is an obstacle to any ship, even an icebreaker, and it is dangerous to those ships which, by their construction, were never really intended for ice navigation. Nevertheless, it is possible for non ice-strengthened ships to navigate through regions of open pack ice. The long hours of summer daylight in high latitudes facilitate such operations.

1103. INDICATIONS OF ICE

a. When ice is expected, but not yet in sight, it is sometimes possible to detect it in the vicinity by certain signs. Radar, for example, is undoubtedly the most valuable aid in giving positive indication of the presence of ice. In a calm sea it should detect large icebergs at fifteen miles and bergy bits and pack ice at three miles.

b. Ice blink, which is the reflection of ice on low cloud, is an indicator much used by experienced navigators. It appears as a diffuse whitish glare above an accumulation of distant ice and is especially noticeable when observed on the horizon.

c. Isolated fragments of floating ice often presage the approach of larger quantities of ice or warn of the presence of icebergs nearby.

d. In late spring, and during the Arctic summer, there is frequently a thick bank of fog over the edge of the pack ice. In fog, patches of whiteness can indicate the presence of ice at short range.

e. Absence of sea or swell, especially in a fresh breeze, can be a reliable sign of ice to windward.

f. A drop in temperature of the surface of the sea, or a drop in the air temperature, can also indicate that a ship has entered waters where ice is likely to be encountered.

g. When clear of land, the sighting of seals, walruses or birds can be a sign of approaching ice.

1104. SIGNS OF OPEN WATER

a. Dark patches on low clouds, sometimes almost black in comparison with the general overcast, can indicate open water, and is known as "water sky".

b. In fog, dark areas discerned through the murk can give a similar indication of open water, but not at any great distance.

c. A dark band of cloud at high altitude indicates the presence of a lead giving access to open water further away.

d. A surging action in the pack ice also indicates the presence of open water nearby.

e. Ideal conditions for ice navigation are fine days with a clear horizon and atmosphere, and with the sky covered by an even layer of cloud. Ice blink will then appear as light markings on the under surface of the clouds above it. Where leads occur in the pack, ice blink will be sharply broken, with "water sky" appearing almost black by contrast.

f. If, when approaching ice, there is darkness on the horizon beyond a light sky, this is good evidence of open water or land lying beyond the ice, in some cases forty miles or more beyond the visible horizon. If dark streaks are observed in the sky, the presence of leads is indicated. If there are no dark streaks, a ship should steer for the place where the ice blink is dullest. Ice blink is increased after a fresh fall of snow, since its reflection in the sky will be whiter from this snow than from the ice.

g. In a cloudless sky there can be no ice blink, though there can be a white haze or glare to indicate the presence of ice. However, in a cloudless sky and calm weather, abnormal refraction may raise the horizon enabling an observer to see ice at greater distances than normally would be possible. The image of ice or areas of open water, or a mixture of the two, may be seen as an erect or inverted image, or both images may be seen at once, one above the other. In this latter case the erect image is the higher of the two. Refraction also causes bergy bits to appear like icebergs. Where there is open water, a dark blue colour will be seen towards which the ship should steer.

1105. ICEBERGS

a. On dark clear nights, icebergs may be sighted at a distance of one or two miles, appearing either as white or black objects. In such conditions bergy bits or growlers constitute a greater hazard to ships. Such pieces of ice may also be difficult to distinguish in daylight, especially in a rough sea.

b. Depending upon its age and position in the sky, the moon may either aid or hinder ice detection. With the moon in front of the observer, icebergs are difficult to see; with the moon behind, blink is thrown off, rendering them visible from a distance in clear weather.

c. A clouded sky at night, through which the moon appears and disappears, makes ice detection difficult. Heavy passing clouds may dim or completely obscure an object sighted ahead. Fleecy cumulus and cumulo-nimbus clouds often give the appearance of blink from bergs.

d. Radar can usually detect large icebergs in ample time to avoid collision, but small bergs and growlers, capable of causing fatal damage even to ice-strengthened ships, may remain undetected under quite moderate conditions of wind and sea. As the state of a sea increases, so does the minimum size of berg that can be detected. (See Figure 4-XIII.)

e. Air temperatures are not a reliable warning of the presence of icebergs, nor are sea temperatures to be depended upon to forewarn of their presence. A small increase in water temperature, caused by fresh water melt from bergs may be noted, but this is of no practical use to the navigator. Sea temperatures are often obtained from the ship's main injections where falsely high readings can make matters even more unsatisfactory.

f. In low visibility the use of a foghorn or siren to detect icebergs by echo is of little use. Sound waves will be reflected only by a high vertical wall of ice, and even then are rarely audible. The absence of an echo is poor evidence that icebergs are not lurking nearby.

g. In daylight, and in clear weather, a ship can usually pick her way through berg-infested waters without deviating materially from her mean line of advance and with a minimum loss of time. But after dark, or in fog, great care should be exercised.

h. It is dangerous for a ship to manoeuvre through a fleet of icebergs in thick weather. She may suddenly encounter one of these ice mountains unseen and, strange to say, sometimes undetected by radar through the fog and moisture, until it is close aboard.

i. It would be unwise to consider making fast to an iceberg in poor weather, for they themselves are often in motion and may carry a ship into heavy pack ice or large floes.

j. There is always a danger that an iceberg may overturn without warning, that it may break up with catastrophic consequences to any ship nearby, or there may be a fall of overhanging pieces of ice. There is no reason, however, why a ship should not take up a position in the lee of an iceberg where a clearing may be found, provided a sharp lookout is maintained.

k. When working through an iceberg-studded sea in low visibility, a well-found ship should reduce speed to a minimum compatible with quick manoeuvring. If compelled to heave-to in heavy weather, a ship should attempt to manoeuvre so as to place her stem against an old floe, using the engines to hold her up into the wind. Should she fall off or drift, serious damage could result from the grinding and surging of heavy floes and there may be no polynya or channel in which to seek refuge.

l. As the greater part by far of an iceberg floats below the surface, they will ground on shoals or in shallow water. The presence of stationary bergs may therefore give some indication of the depth of water in their vicinity. For example:

(1) An accumulation of stationary bergs often marks an isolated shoal.

(2) A line of grounded bergs extending seaward from the shoreline, or between an island and the mainland, may indicate the presence of a submerged ridge or shoal.

(3) A shoreline fringed by glaciers, or studded with icebergs inshore but free of ice to seaward, would indicate that the shoreline falls off steeply into deep water.

(4) A bay in which icebergs are found must have a deep channel leading into it. The sides of a channel which are bordered with icebergs, but with its centre clear, may invariably be considered safe. Open water will usually be found during the summer months along a coast where offshore winds prevail.

1106. ENTERING THE ICE

a. When a ship encounters ice lying athwart her course, a decision must be made whether to penetrate it or to skirt it. If its boundaries are visible it is wiser to go around it to windward. In the case of large icefields, unless they fill straits through which a ship must pass, it will generally be more economical in fuel and time to take the longer way around.

b. "Water sky" can indicate a direction in which ice conditions may be more favourable, while "ice blink" will indicate areas to be avoided. Keep away from the weather edge of pack ice and avoid ice under pressure and churning ice. Grounded and hummocky ice in the pack and floes of polar ice should also be given a wide berth.

c. Before committing a ship to the pack, a complete reconnaissance of the area should be undertaken, using every means available – radar, lookouts, helicopter observations and ice reports from long range fixed wing aircraft. The point of entry should be carefully selected and the ice entered at right angles, after which the ship should make for the loosest areas in the pack. Preferably make the entry upwind, remembering that the windward edge of an icefield will be more compact than its leeward edge. The violent motion of ice from the action of the waves will also be damped out on its leeward side.

d. Avoid a lee shore on which ice is usually dense and hummocky. Favor a windward shore where an open channel may be found. Do not manoeuvre so closely to points of land that a combination of wind, ice, and unknown currents could force the ship aground.

e. If the ice is drifting rapidly, wait (preferably in open water) and hope for a change in direction of the ice movement which may be accompanied by an improvement in conditions. Take into account the times of ebb and flood tide; ice tends to compact on the flood and to loosen up on the ebb.

f. An ice edge is usually not straight, but often has tongues projecting between bights. Select a suitable bight and enter there where the surging action will be least.

g. Enter at slow speed to reduce the initial impact on the stem. Once the bow is in the ice, cutting and pushing it aside, power should be increased to avoid losing headway.

h. Give all icebergs and other forms of glacial ice in the pack a wide berth. In a non ice-strengthened or ice-strengthened ship, if a collision with a floe is inevitable, it is best to take the blow on the stem while going astern at full speed. Icebreakers, however, are so stoutly built that they are not necessarily obliged to act in this fashion.

i. Navigation in pack ice after dark, or in fog, or when the ice is under pressure should not be attempted.

j. Propellers are the most vulnerable part of a ship, and conning officers in twin-screw ships must see to it that whenever heavy ice approaches the stern, action is taken to slow the shaft on the threatened side. Single-screw ships are not immune, for heavy ice can sometimes find its way under the ship where it will work along the keel to surface under the propeller and rudder causing serious damage.

k. It should be remembered that if the bow of a ship rebounds off a floe the stern may be swung into heavy ice with a risk of damage to rudder and propellers.

1107. SPEED OF SHIPS WORKING IN ICE

a. Pack ice, unless it is widespread and loose, should be entered going dead slow. Speed should be increased only after assessing the general state of the ice and the extent to which it will be possible to get through it undamaged.

b. Speed through ice must be a matter of judgement and will depend, among other things, upon the amount of open water, the hardness of the ice and the strength of the ship. It is dangerously easy to underestimate the hardness of ice. A better course of action, if there is an option, might be to enlist the services of an icebreaker or to seek another route.

c. Try to maintain steerage way, as otherwise there is no control over the ship which, in turn, is an invitation to ice damage. Coasting into ice, with engines stopped, will probably result in loss of steerage way.

d. A ship may also be thrown out of control should she strike a piece of ice a glancing blow.

e. At any time ships should be prepared to go "Full Astern". "Stop" means the propeller must be stopped – by backing steam or power if necessary. However, a slowly turning propeller is less susceptible to ice damage than one completely stopped.

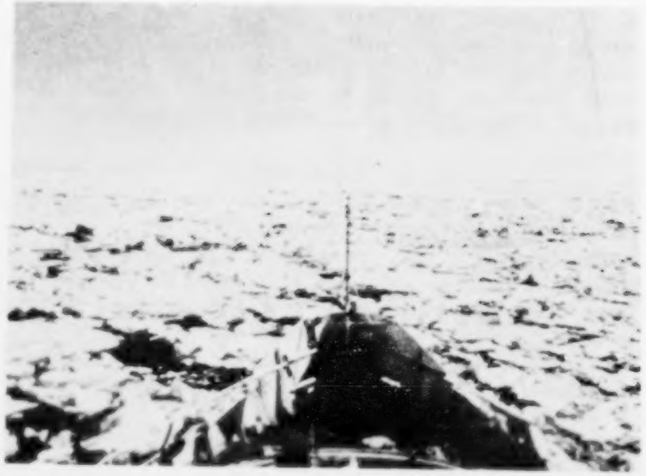
f. In less than five-eighths ice, the speed of a ship passing through the ice, without icebreaker escort, should depend on the distribution of leads and pools of water. If the distribution of ice is suitable for navigation, higher speeds may be attempted.

g. Six- to seven-eighths ice should be negotiated throughout at slow speed, so that collision with floes will not damage the hull. Generally speaking this is no place for non ice-strengthened ships when the ice is of Arctic origin.

h. In the dark, or when visibility closes in, a ship working her way through leads in close pack should heave-to. If she continues, she may unwittingly blunder into even thicker ice from which it may be difficult to extricate herself later when conditions improve. When moving through very loose pack at night, or in poor visibility, it may be worth continuing but with caution and at slow speed. In such circumstances searchlights, preferably mounted in the eyes of the ship, can be of considerable help.

1108. WORKING THROUGH ICE

a. The extent of the ice should be studied from aloft, preferably from a helicopter. In this way distant leads and open water, invisible from the bridge, may be revealed. The character of the ice ahead, when viewed from aloft, may sometimes be assessed by comparing it with the ice through which the ship has just passed. Pressure ridges and ice which is greenish-blue in colour (polar ice) should be avoided.



b. When a long-range ice reconnaissance aircraft is available, it should be used accordingly. The nature and extent of the ice can be observed from the air for many miles and a ship can exploit the most promising openings trending in the desired direction. Sometimes such a survey will indicate the advisability of a ship making a detour, skirting the pack and reaching open water, the existence of which would otherwise have remained unknown.

c. Helicopters are unmatched for ice reconnaissance within the immediate area of a ship. It is best if a ship can carry her own helicopter, thus providing the very best possible "crows-nest" view of ice conditions.

d. Ideally, and if conditions permit, long-range fixed-wing ice reconnaissance aircraft should fly their missions between 1,500 – 2,000 ft., although in certain circumstances high flight levels may be more effective. In conditions of low visibility such aircraft may have to fly higher than 1,500/2,000 ft., but to be effective under such conditions they must be properly equipped and manned by skilled observers to produce data of any value.

e. Sometimes pools of melt water form on top of the ice. From the air, to an inexperienced observer, and even from a distance at sea level, these resemble open pack. Upon closer examination it will be found that the ice is continuous under the pools and may even be unnavigable. In such circumstances an erroneous ice report could result in loss of time.

f. Aerial ice observers should be thoroughly trained and familiar with the problems confronting the ships to which they are passing important information. To provide continuity, the same ice observers ought to be used, and such observers must have the confidence of the captains, who may have to rely heavily upon their reports.

g. At slow speeds, ships answer their helms badly and are slow to turn. Short ships turn more readily and are easier to manoeuvre in ice. A short burst of full speed ahead, with the helm over, may be of assistance in speeding up a turn to avoid a floe. Propellers and rudder may be afforded some protection by trimming by the stern, but if overdone this can impair a ship's manoeuvring properties.

h. A twin screw ship, other than an icebreaker, is at a disadvantage in ice because of the vulnerability of her propellers, although she has greater menoeuvrability. Setting a watch on each bridge wing, with authority to take action on the appropriate engine room telegraph when a particular propeller is endangered by ice, is one possible safeguard.

i. Ships should go astern in ice with extreme care, always with their rudders amidships and while keeping a sharp outlook for ice under the quarter. One system for working astern in ice is to:

(1) Allow propellers to wash the ice astern for a few minutes before going astern.
(2) Go full astern until just before contact with the ice debris, then stop and allow the momentum to carry the ship into the churned-up ice.
(3) When all ice has surfaced, give a short burst of ahead power and stop.
(4) Repeat this process until sufficient manoeuvring room has been produced.

j. Another effective system for working a twin-screw ship astern, when surrounded by heavy brash, is to:

(1) Go astern on one engine while going ahead on the other, setting up a current under the stern which opens up an area of clear water to one side depending upon the engine direction.
(2) Go astern on both engines. This should move the stern into the open area until the ice eventually brings the ship to a halt.
(3) When stopped, repeat backing on one engine and going ahead on the other, but in the combination opposite to that used previously, until an open area of water appears on the other side.
(4) As in (2) above.

k. A ship should attempt to force her way through pack ice only when the ice is not under pressure because of the influence of wind and current. Avoid pressure ridges. Cracks may form in ice fields along a line of pressure perpendicular to the movement of the ice. Such cracks are sometimes ridged. At the least change in wind or current, these heavy masses may come together crushing and grinding anything caught between them.

l. Fine weather in the pack often portends lower temperatures, close pack and little open water, whereas damp and misty weather generally signifies the presence of some open water and better conditions for manoeuvring. The presence of swell indicates loose pack is near at hand and open water not very far off.

m. Any off-shore wind usually creates a channel between the coast and the pack. If this is exploited by a ship, she should be alert for an onshore wind driving the pack back onto the coast if the latter is steep-to. In such a case, shelter should be sought in a bay or behind an island. Failing any such refuge, the only alternative would be to go out and meet the ice hoping to work through it to open water.

n. *Icebergs in the pack should be given a wide berth, as they are current-driven, while the pack is wind-driven.* They generally move at a different rate from the sea ice, and in strong currents may even travel upwind, wrecking heavy pack on their way and endangering any ship in their path which is unable to work clear. In these conditions, open water will exist to leeward and piled-up pressure ice to windward of bergs. Similar conditions have been observed in regions where currents are weak. In a strong wind the pack may overtake the bergs, resulting in a heaping up of the pack to windward, while a lane of open water opens to leeward of the bergs. This creates the illusion that the bergs are travelling in a direction opposite to the pack.

o. If it becomes necessary to heave-to in a polynya, it is not always desirable to do so in the vicinity of icebergs because, as the latter do not move with the pack, the opening is apt to close up. Furthermore, growlers often occur in the vicinity of bergs. If a ship is made fast to an ice floe or is sheltering in one, unceasing watchfulness is necessary for eddies and currents, and a weather eye must be kept on bergs or heavy ice that may be near, lest they approach without perceptible motion.

p. The movement of a berg through wind-compacted ice creates a lead which may remain open for a time. In traversing pack, advantage might be taken of such leads.

q. If a ship enters a narrow strait or bay, into which the prevailing winds are known to blow, she should be alert to the possibility of ice being driven in by a sudden change in weather and trapping her there.

r. A ship should exercise caution when to windward of a prominent headland because a sudden increase in the wind may drive the pack down upon the vessel which, if set toward a lee shore, may become heavily beset and subject to pressure. An exception to this occurs in the western Canadian Arctic and along the north Alaskan coast where ships successfully navigate close inshore, depending upon their draught, thus avoiding the heavy pack lying to seaward.

s. When suspending operations because of darkness, or for any other reason, icebreaker captains often prefer to heave-to by driving their ship into the midst of a convenient floe and parking there for as long as desired. This technique is safe, easy, and effective. Hands to work anchors and cables are not required, the loss of ground tackle is not risked and in deep water where anchoring would be impossible anyway, such parking is a perfect solution.

t. If care is taken, there is no reason why other ships, both ice-strengthened and non ice-strengthened, cannot do likewise. In deep water such a tactic is better than drifting in the open sea and being exposed to potential damage from heavy floes

1109. CONVOYING IN ICE

a. An ice convoy consists of one or more ships, some of which may be strengthened for ice navigation, accompanied by one or more icebreakers.

b. It is essential that such a convoy, while in ice, be under the direction of the commanding officer of the leading icebreaker. Should the senior officer of a naval force happen to be embarked in a ship without icebreaking capabilities, he must delegate tactical control to the senior icebreaker captain.

1110. TYPES OF CONVOY

a. There are two types of ice convoy:

(1) Simple convoy: one icebreaker escorting a group of ships.
(2) Composite convoy: two or more icebreakers escorting several ships.

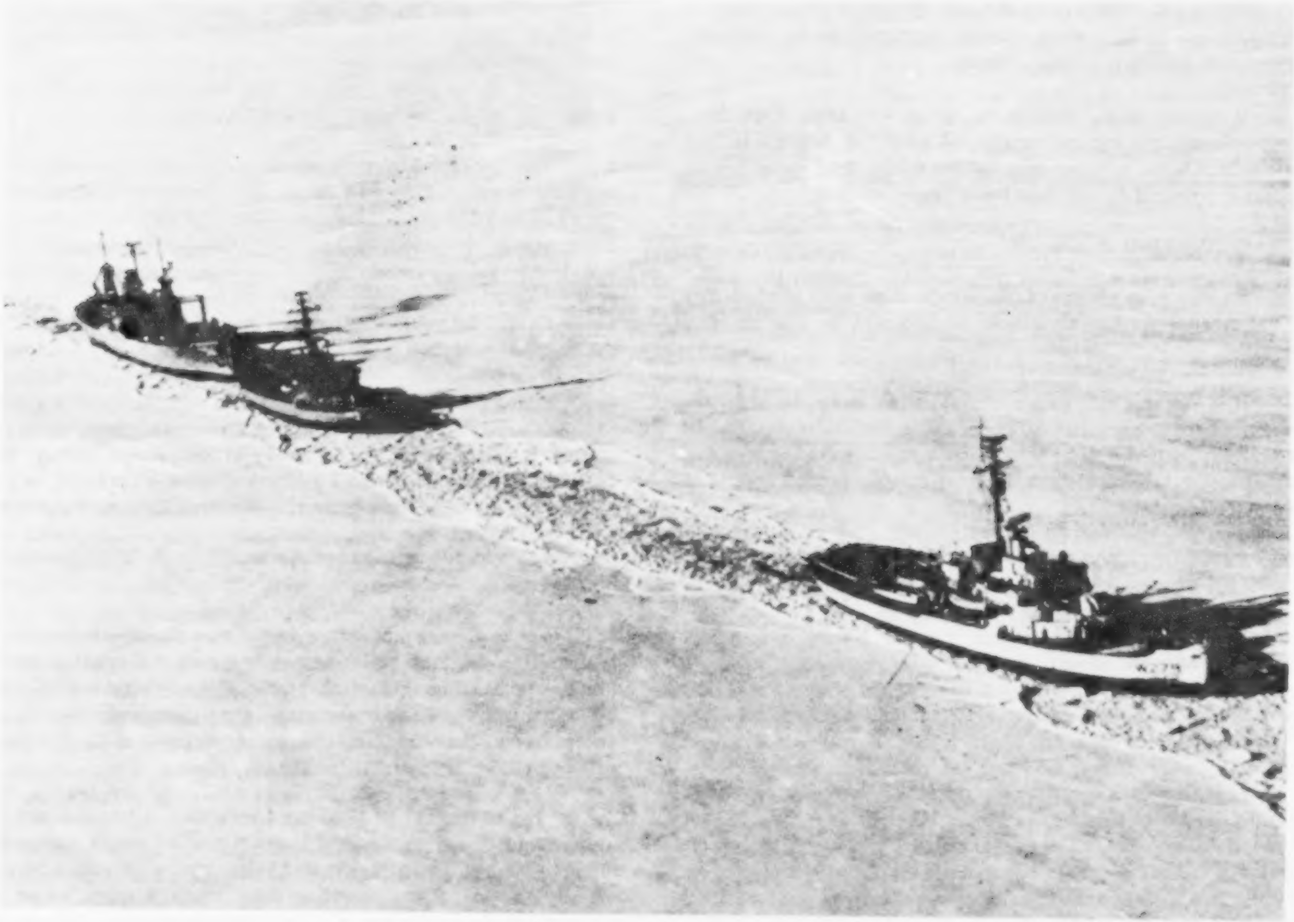
b. For a simple convoy, the captain of the icebreaker will decide upon the number of ships he can handle. His decision will depend not only on the number, but on the power and type of ship requiring escort and the ice conditions expected en route. If the ships are reinforced for ice navigation, and have sufficiently powerful engines, one icebreaker can usually escort four of them through six- to seven-eighths ice. In four or five eighths ice or less, the number of ships can be increased. If there is close pack (more than seven-eighths) only one or two ships can be handled. In attempting to conduct too large a number of ships through close pack, it would be necessary for an icebreaker to fall back continually to break them out, thus losing valuable time.

c. The first factor to be considered must be the power of the ships requiring escort. The weakest, as a rule, should be stationed immediately astern of the icebreaker to avoid ice obstacles and to move in a comparatively clear channel. The most powerful and beamiest ships would be placed in a convoy so that less powerful ships could proceed in their wake. Consideration should also be given to the matter of whether a ship is loaded or in ballast. Finally, it is essential that one of the most powerful ships in the convoy be last in line.

d. A composite convoy consists of two or three simple convoys. The number of ships allocated to each icebreaker, and their place in the column, is determined in the same way as for a simple convoy. The difficulty of controlling from a position ahead is a drawback in this type of convoy, which frequently extends over a distance of two miles or more. The first or leading icebreaker is designated the leader, the others are stationed according to the orders of the leader's commanding officer.

e. The customary procedure is for the most powerful icebreaker to lead the convoy, breaking a channel in the ice without stopping to break out other ships. Following the leader, at a distance decided upon by her captain, come two or three ships, the weakest and longest in the entire convoy. The second icebreaker proceeds astern of the first group followed by two or three ships, and so on.

f. The assignment of the second icebreaker is to break out the ships ahead of her so that the leader will not have to return, thus delaying the whole party. The second icebreaker, on receiving a "stuck" signal from any of the preceding ships, increases speed, leaves the column and breaks out that ship. When the latter is freed and moving,



the icebreaker resumes her previous position in the column. Similar action is taken by the second icebreaker upon receiving the same signal from one of the ships astern, provided there are no more icebreakers available. If there is a third icebreaker, she breaks out the ships following the second icebreaker.

1111. DISTANCE BETWEEN SHIPS

a. Before entering the ice, the captains of all ships should understand the importance of maintaining the agreed distance between their ships and the icebreakers, and between other ships, as ordered by the senior icebreaker captain, who must, however, watch his next astern constantly and drop back if the escorted ship obviously cannot keep up.

b. If ice conditions are not too heavy, say less than six-eighths, ships ought to be able to follow an icebreaker without too much difficulty. The beaminess of the leading icebreaker makes it easy for the ships closest to her but, as the channel closes in farther astern, ships at the end of the line may encounter difficulties. It is, therefore, unwise to have the convoy strung out in too long a line. At the same time the distance between ships should be great enough for way to be checked and collision averted if a "stop" signal is originated by any one of the icebreakers. As a rule, way in merchant ships of average tonnage can be checked in ice-free waters by going astern over a distance of three to three and a half ship lengths, provided an order for full speed astern is given. This distance should, therefore, be the minimum between ships when navigating in less than six-eighths ice.

c. Depending upon ice conditions, very large ships (i.e., those displacing 100,000 tons or more) must of course keep very much farther apart. Until more experience is gained in convoying ships of this size through ice, at least half a mile is recommended as a minimum. Even that distance would probably be hopelessly insufficient for a deep draught giant cargo vessel to check her way in time to avoid over-running her next ahead in the event the latter becomes stuck.

d. A channel made by an icebreaker will eventually fill with broken ice. The difficulties caused by this to a ship in a narrow channel increase when the distance between ships is increased, and even powerful ships may find their speed greatly reduced. This makes it all the more important for ships to maintain the minimum prescribed distance apart. Signals from the leading icebreaker must be obeyed promptly and correctly and all ships must be alert for any difficulties and delays caused by ice.

e. When negotiating more than six-eighths ice, the distances suggested above should be reduced. To avoid damage from ice floating in the cleared channel, a ship should carry a little headway. If the ice is completely unbroken and under considerable pressure, the distance between ships may be reduced to a few yards. In these circumstances a cleared channel will quickly be covered by ice, leaving only a small lead astern of the icebreaker. If a ship remains at a distance of two or three ship lengths from the icebreaker, the cleared passage achieved by the latter will be lost.

f. Handling a ship in convoy at reduced distances requires experience on the part of both the icebreaker and the ships being escorted. In heavy ice there are frequently obstacles which an icebreaker cannot overcome on the run. She may unexpectedly stop and give the signal "Full Astern" to the following ships. To avoid a collision they must go astern immediately. When moving in such close formation, the nature of the ice ahead must be assessed most carefully by the icebreaker so that fluctuations in speed can be anticipated, and a warning passed to ships astern in good time. The danger resulting from a sudden stop on the part of the icebreaker is obvious; hence the importance of maintaining the correct distance applicable to the ice conditions. Spacing must be changed to suit varying conditions of ice, and great emphasis laid on accurate station-keeping.

g. By virtue of his experience and his position in the convoy, which enables him to assess as well as sample the ice conditions ahead, the captain of the leading icebreaker must be the one to decide upon the spacing to be maintained between the ships under his charge.

h. It is essential that Commanding Officers and Masters of escorted ships be thoroughly familiar with the signals used for convoying in ice. It should never be necessary for an icebreaker to have to repeat a signal. (See Article 1114 – Signalling Between Icebreakers and Escorted Ships.)

1112. COURSE AND SPEED OF CONVOY

a. The longest safe route in open water will generally be quicker than a more direct one in ice, and the selected track should pass through areas of thin ice or open water, regardless of the length of the voyage. Course changes should be gradual since most cases of ships getting stuck occur when sharp turns are made by the much more manoeuvrable icebreaker. Speed must be decided upon by the captain of the leading icebreaker. Speed over the ground through the pack usually varies between 4 – 7 kt. The higher speed is desirable due to better manoeuvrability of large ships, but ice conditions must be the governing factor.

b. In a convoy composed of ships reinforced for ice navigation, a speed over the ground of 6 – 7 kt. can be maintained if the route lies through four-eighths open pack, and if the captain of the leading icebreaker is certain that the ships following him will not meet with heavy ice. Ships following an icebreaker should be aware of the danger of passing close to large floes. If a ship cannot keep off the ice, she should ask the icebreaker to widen the channel. The enormous size of modern ships means that an icebreaker's path frequently will not be wide enough.

c. When navigating in close pack (six- to seven-eighths), speed over the ground should not exceed 5 kt. In such ice a convoy will be moving in a channel which will not remain navigable for very long after the passage of the icebreaker. Therefore, the distance between ships must be reduced to enable them to move in as clear a channel as possible. Higher speeds not only increase the danger of hitting the ice, but also the possibility of colliding during unscheduled stops of the icebreaker or other ships of the convoy. If a single-screw ship must suddenly go full astern without warning while passing through an ice-covered channel, her stern will kick to port and her bow to starboard. This could damage the propeller, rudder and starboard side of the ship. To avoid collision with a ship ahead, it is preferable to ram the ice on one side of the channel, bow foremost, rather than risk damage to the rudder and propeller by going astern in heavy ice.

1113. CONDUCTING THROUGH ICE

a. When following an icebreaker a convoy should keep in line. If the former alters course, all ships should follow in succession to the new course. By looking for independent channels ships break up formation and may become stuck. The icebreaker is then compelled to return and break out each ship separately, thereby delaying the whole passage.

b. Since headway through heavy floes and ice fields is more difficult than through "normal" pack, an icebreaker increases speed and, by striking the ice, crushes or breaks it. Ships astern must maintain correct intervals and endeavour to enter the channel thus made before it closes.

c. If an icebreaker should encounter an obstacle where a glancing blow is struck by her stem, she will be thrown sideways. Ships following behind may be too unwieldy, or be unable to react quickly enough, and may suffer damage. This is particularly applicable to single screw ships. This sudden change of direction should be expected when moving through ice of varying structures and strength. In such circumstances an icebreaker should not make too rapid a return to her original course.

d. In summer there are many signs indicating the state of the ice. Careful observations should be made to determine whether the ice has been softened by the sun or if it still retains its winter hardness. Greenish or greenish-blue ice is the hardest to break and such ice should be outflanked. This type of ice is sometimes covered with pools of clear melt water formed during the thaw of snow on the surface of the ice. If sections of dirty looking ice are encountered, in areas of light coloured ice, the former should provide the easier route, since the darker ice absorbs more heat from the sun and melts sooner.

e. The most navigable type of ice is brash, even though it may be devoid of leads. Although this ice usually closes up as a result of tide and wind, it consists of separate cakes and does not present a serious obstacle. When the pressure is great, however, even though an icebreaker can get through, a ship astern may be hindered as the channel behind the icebreaker closes up immediateley. In brash, even under pressure, ships are in less danger than if they were being pressed by larger and heavier forms of ice.

f. When hummocked ice is met, an icebreaker should first attempt to outflank it. The outward characteristics of hummocky ice may indicate to what extent it will be navigable. If the hummocks consist of loose blocks not fused together into one solid piece, they may easily be overcome, but if they are composed of larger masses of ice many feet thick, they will be impassable even to an icebreaker.

g. In close pack there are places where even an icebreaker cannot penetrate. The great friction created by ice against an icebreaker's sides may compel her to stop. The power of her engines in such cases is insufficient and she gradually loses way. Such ice can be handled only by backing and ramming.

h. Usually an icebreaker backs up one to three ship lengths, then goes full ahead until her stem attacks the ice. If the ice is strong and extends over a great area, this process must be repeated for many hours and progress will be very slow.

i. If the ice is not broken after one blow, the icebreaker loses momentum and stops. Sometimes she experiences difficulty in backing clear, but by using her heeling and trimming tanks, in conjunction with her powerful engines, she will eventually get clear.

j. It may be necessary to make either a simple channel, equal to the beam of the icebreaker, or a double or triple one, depending on the strength and character of the ice and on the size of the ships waiting to get through. After carving a channel of the appropriate width, the icebreaker returns to the ships awaiting escort and, provided the channel remains open, she will be able to lead two or three ships at a time.

k. While navigating in heavy ice, there is danger of damaging not only the escorted ships but the icebreaker as well, even though the latter are well equipped for fighting ice. The draught of a ship is also of importance, since the water-line plating is usually the strongest. Ships should be so loaded and trimmed that only this strongest plating will be in contact with ice. In the after part the propeller is exposed to danger. In fact, while in ice, it is the most vulnerable part of the whole ship. It is often assumed that blades are damaged only when a ship is going astern. This is not true. Blades can be damaged or lost while going ahead as well. Sometimes large blocks of ice pass under the ship's hull and turn on edge. Such ice is dangerous and can damage propellers.

1114. SIGNALLING BETWEEN ICEBREAKERS AND ESCORTED SHIPS

a. Suitable signals which have been adopted for use are given in

W279

Chapter 13 of the revised (1969) International Code of Signals and may be used between icebreakers and ships navigating in their vicinity or under their escort.

b. The signal "K" (–.–) by sound or light may be used by an icebreaker to remind ships of their obligation to listen continuously on their radios.

c. The use of the special signals from the International Code of Signals (1969) does not relieve any ship from complying with the International Regulations for Preventing Collisions at Sea.

d. Whistle signals are limited in their value. Experience has shown them to be of questionable value in a convoy of several ships because of the time lag and the danger of misinterpretation. Whenever possible, voice radio should be used and, when ships are close aboard, loud hailers can be used very effectively.

1115. STOPPED ICEBREAKER – RED WARNING LIGHTS AND SOUND SIGNAL

a. Canadian icebreakers escorting ships in ice make use of two special rotating red warning lights to indicate that icebreakers are fouled or jammed in ice.

b. These two red lights are disposed in a vertical line, one over the other, about six feet apart and they are visible all around the horizon at a distance of two miles. They rotate in a manner similar to the lights on air beacons and are unmistakable as warning lights.

c. The rotating red lights operate in conjunction with a motor-driven siren, facing astern, audible up to a distance of about five miles depending upon atmospheric conditions.

1116. BREAKING OUT SHIPS

a. When a ship is beset, awaiting icebreaker assistance to get her moving again, she should attempt to keep her propeller(s) turning, albeit slowly, to keep the ice away. If she lies there with engines stopped, as is advised in some quarters, ice will move in around the stern making it impossible, even dangerous, to start turning her propeller(s) at the moment the icebreaker has created an opening for her to exploit.

b. Should the icebreaker captain ask for the propeller(s) to be stopped, the beset ship must, of course, immediately comply with the request.

c. Icebreakers usually prefer to drop back stern-first from ahead until abeam of the stuck ship. They then move ahead, instructing the latter to follow, a manoeuvre which will obviously be greatly facilitated if the escorted ship's engines are already turning over. The open water left by the icebreaker should be immediately occupied by the beset ship. If she hesitates it will be too late and ice will fill it instead.

d. Most icebreakers dislike coming up from astern of a beset ship for fear of shoving ice under the latter's stern, jamming her rudder and propeller(s), thus making a bad situation worse. Should this happen, the beset ship would be unable to occupy any opening in the ice and matters would be even further delayed. Similarly, icebreakers should be careful not to push heavy floes against the sides of thin-skinned ships, which could rupture their plating.

e. There are many ways in which an icebreaker can free a beset ship and no attempt is made to cover them all here. Every icebreaker captain has his own ideas and theories on how best to perform the manoeuvres required to accomplish his task. Ice conditions also have a bearing on the tactics to be used. However, icebreaker captains will always communicate their plan to the ship to be helped, which must, in her turn, do everything she can to assist.

1117. INADVISABILITY OF TOWING

Towing in ice is an extremely hazardous operation due to the inconsistencies of speed resulting from the varying thicknesses of ice. Captains of ships should not consider being towed at any time unless an unquestioned emergency exists. An icebreaker captain receiving a request for a tow shall himself judge whether to use his ship for this purpose in ice.

1118. REPLENISHMENT IN ICE

a. Replenishment in ice can be accomplished only when both ships are stopped and lying as close aboard each other as practicable. Prevailing ice conditions should be carefully studied to ensure that replenishment can be completed safely. Pack that is drifting into a lee shore must obviously be avoided.

b. When approaching another ship in the pack there is a danger that the pressure generated by the approaching ship will force intervening ice blocks through the plating of one or both ships, or will damage rudders and propellers of the ship approached.

c. A bow to bow approach is generally safest for berthing alongside another ship. If an icebreaker is available, she should proceed carefully through the ice ahead of the ship making the approach.

1119. ANCHORING

a. Anchoring in the presence of ice is a risky business at the best of times. Should it become necessary, however, great caution and vigilance must be exercised to prevent damage to, or loss of, ground tackle. The minimum amount of cable should be paid out and the capstan must be available for immediate use in case heavy pack ice approaches the anchorage.

b. When anchoring in rotten ice or in shoal water, a ship should first attempt to penetrate the ice as far as necessary to avoid any swell. If the water is deep and ice is present, anchoring should be avoided. In such circumstances it is preferable to heave-to, keep power available and manoeuvre as necessary to avoid floes which may approach and threaten the ship.

CHAPTER 12

ARCTIC NAVIGATION, NAVIGATIONAL AIDS AND PILOTAGE

1201. GENERAL

It is more difficult to navigate accurately and successfully in the Arctic than in more temperate regions due to climatic factors, a lack of accurate charts and a lack of navigational aids.

1202. CHARTS AND SAILING DIRECTIONS

a. Requirements for charts and related publications can be met from the following sources:

(1) *Catalogue of Nautical Charts and Publications* published by U.S. Naval Oceanographic Office, Washington, D.C.
(2) *Catalogue of Nautical Charts and Publications* published by Canadian Hydrographic Service and available from the Queen's Printer, Ottawa, Canada.
(3) *Catalogue of Admiralty Charts and other Hydrographic Publications*, published by the Ministry of Defence (Navy), London, England.

b. American and British authorities also publish classified catalogues describing selected classified charts and publications embracing Arctic areas.

1203. GENERAL REFERENCE BOOKS

A number of Arctic navigational reference books are available and are listed in Art. 1219. The Arctic navigator must provide himself with all his necessary references prior to sailing for northern waters.

1204. CHART PROJECTIONS

a. The Mercator projection satisfies the navigator's needs to the 70th parallel of north latitude. In latitudes higher than 70°N, however, the usefulness of the Mercator projection decreases rapidly, primarily because the value of the rhumb line becomes progressively less, and because there is an increasing rate of change in chart scales.

b. Chart producers generally opt for a more appropriate projection for Arctic use. The four most commonly used are:

(1) Transverse Mercator Projection – particularly when considering areas extending north-south.
(2) Modified Lambert Conformal Projection.
(3) Polar Stereographic Projection.
(4) Polyconic Projection.

1205. POLAR GRID

Because of increasing convergence of the meridians near the pole, the true directions of an oblique course line will vary considerably depending upon the length of the course line and its proximity to the pole. A polar grid provides the navigator with the changing true direction. The polar grid is described in the *H.O. Publication No. 9*, Chapter XXV – Polar Navigation.

1206. MAGNETIC COMPASSES

a. The directive force of the magnetic compass is derived from the horizontal component of the earth's magnetic field. Although the total intensity of the earth's field remains fairly constant in all latitudes, the horizontal component decreases as the magnetic poles are approached, until the directive force becomes so weak that the compass is apparently insensitive and unresponsive.

b. Conversely, the vertical component increases and may give rise to large heeling errors. Although the horizontal component of the earth's field, and hence the induced magnetism in horizontal soft iron, decreases as the magnetic poles are approached, the field of sub-permanent magnetism of the ship's structure retains its absolute value and therefore becomes relatively much more important in causing deviation. Small uncompensated deviations due to sub-permanent magnetism may attain very large values in high latitudes.

c. Furthermore, magnetic disturbances or magnetic storms cause fluctuations in magnetic variations. For example, a severe magnetic disturbance can shift the effective position of the magnetic pole as much as 100 miles or more.

d. The Canadian Hydrographic Service publishes Canadian Chart Number 10200 – *Magnetic Chart of the Canadian Arctic*, depicting areas where the magnetic compass will be erratic, unreliable or useless. This same chart depicts lines of equal mean daily range of magnetic variation.

e. To obtain the best performance from the magnetic compass in Arctic waters, a ship should be swung and her compasses adjusted in high latitudes, preferably before entering the pack ice. If the Flinders bar has not been permanently set at the magnetic equator, it must now be adjusted to the position indicated by computation, and the horizontal and heeling magnets carefully placed to produce minimum deviation.

f. Even if this recommended procedure is followed, changes in magnetic latitude may cause large deviations to reappear. Likewise the magnetic variations will change rapidly with locality and may undergo large diurnal changes, particularly if auroral activity is present, so that the navigator must undertake frequent azimuth determinations. If large compass errors are found, and if it is uncertain whether these are due to variation or to deviation, swinging the ship again to see whether the error persists on all headings will establish the cause.

g. Provided that seamanlike precautions have been taken (e.g., burning the binnacle light continuously and keeping the binnacle itself covered by canvas when not in use), the liquid in modern magnetic compasses is capable of withstanding Arctic temperatures.

h. The fluxgate compass has proved to be quite sensitive and has given fairly accurate and reliable results. The Admiralty gyro-magnetic compass with a pivoted card has proved to be serviceable for navigation up to 200 miles from the north magnetic pole, and has the additional advantage of being available as a simple magnetic compass should power fail.

1207. GYRO COMPASSES

a. When operating north of 70°N, particular attention should be paid to the operation of gyro compasses and associated equipments. Manuals on military gyro compasses usually specify 85°N as the highest latitude at which a gyro compass will function reliably as a direction-indicating device.

b. Between the latitudes of 70° and 85°N, gyro errors may be considerable. Therefore, when weather conditions permit, frequent azimuths of heavenly bodies are recommended. For certain gyro compasses nomographs are available in operating manuals, and certain gyro compasses are capable of being fitted with high latitude correctors which improve performance above 70°N.

1208. AZIMUTHS

Every opportunity should be taken to determine the errors of compasses, particularly by azimuths of the sun. An azimuth attachment for a telescopic alidade is recommended; it may be of value in obtaining accurate azimuths for determining gyro error when the sun is not brilliant enough to obtain an azimuth by the use of an azimuth circle. The present azimuth tables for high latitudes can be used only during a certain portion of the day, but azimuths for use at any time can be computed.

1209. CELESTIAL COMPASSES

a. Where magnetic and gyro compasses cannot be relied upon to provide trustworthy directional references, a navigator should consider using:

(1) *The Sun Compass.* This indicates direction by means of a shadow cast by a shadow pin. This instrument is, of course, of use only when the sun is visible and the observer knows his position.

(2) *The Astro-Compass.* This is similar in principle to the Sun Compass, but may be used with any celestial body.

(3) *The Sky (or Twilight) Compass.* This compass indicates direction by means of the polarizing effect of the earth's atmosphere on sunlight. Its usefulness arises principally from the fact that twilight periods in high latitudes are of several hours duration and during this time no celestial body is visible unless the moon or a bright planet is above the horizon.

1210. DEAD RECKONING

a. When steaming in poorly charted waters, a ship can run aground or expose herself to other unexpected hazards. Because of inadequate tidal information, as well as other shortcomings, the most accurate estimated position may not result in an exact position. But careful reckoning, in accordance with the suggestions outlined in the following paragraphs, may be of help to the navigator.

b. Maintaining a dead reckoning position between observations, while seeking a passage through ice when out of sight of land, poses special problems. Nonetheless, it is recommended that such a dead reckoning track be maintained continuously as a quick reference. Conventional methods of dead reckoning, and indeed most accepted pilotage techniques, cannot always be practised successfully in ice-strewn Arctic waters. Chart inaccuracies compound the problem of maintaining an accurate record of a ship's movements.

c. Inaccurate charts, together with limited fixing marks, may compel the navigator to resort to "relative navigation", i.e., fixing relative to selected charted landmarks or other objects. Acceptance of this method of fixing and assessing the accuracy of the ship's track, makes navigation and pilotage in the Arctic a less precise matter than is the case in lower latitudes.

d. Courses and speeds change continuously and do not lend themselves to accurate calculation, as a ship picks her way around ice floes. But estimated courses and speeds over the ground should still be noted.

e. Repeated alterations of course to avoid ice make it extremely difficult to plot a ship's track on a chart – especially a small-scale one. Plotting the mean course and distance made good, on the chart in use, once or twice each watch is therefore recommended. To obtain this information it is first necessary to carry out subsidiary plotting, for which a plotting sheet or squared paper should be used if a large scale chart of the area is not available.

f. When navigating in poorly charted waters, it is essential to fix the ship's position constantly using every means available.

g. Plotting the positions of large icebergs, especially if they are known to be aground, can sometimes be most useful as an aid to navigation when identifiable landmarks are not available. This is a good example of "relative navigation".

h. Bottom soundings should rarely, if ever, be relied upon to assist in maintaining a dead reckoning position or for fixing the ship.

i. Non-stop vigilance plus efficient radars and echo sounders should, in most instances, enable the navigator to operate effectively and safely in Arctic waters.

1211. ASTRONOMICAL OBSERVATIONS

a. For a great part of the navigation season, cloud or fog obscures the sun in the Arctic, while continuous daylight prevents stellar observations. Ice horizons and abnormal mirage may also complicate the task of obtaining a precise altitude of the sun during periods of good visibility.

b. Because of climatic factors, celestial observations cannot be counted on. Fog and low cloud ceilings, combined with horizontal disturbances, limit the availability of celestial sights during the months when ice conditions permit navigation. Extensive daylight throughout the summer aggravates the situation.

c. Standard refraction tables are not accurate in high latitudes. *H.O. Publication 214* does not allow for solution of the celestial problem for observed altitude of less than 5°, a common condition in the early and late summer periods.

d. The use of a bubble sextant, bubble attachment to the standard sextant, or artificial horizons can be helpful.

e. Even when accurate celestial position lines have been obtained, they can be of doubtful value, as the navigator may be faced with the difficulty of relating celestial position lines to inaccurately charted positions of landmarks.

f. Despite these formidable limitations, celestial observations should not be ruled out. The following chapters of *H.O. Publication No. 9 – American Practical Navigator*, are recommended reading during "in harbour" preparations:

(1) Chapter XVI – Sextant Altitude Corrections.
(2) Chapter XX – Sight Reduction.
(3) Chapter XXV – Polar Navigation.
(4) Chapter XXIX – Navigation Errors.

1212. SUNRISE, SUNSET AND TWILIGHT PHENOMENA

Tabulated local mean times of Sun/Moonrise, Sun/Moonset, Nautical Twilight and Civil Twilight listings go no higher than 72°N in Nautical Almanacs. In latitudes higher than 72°N, the graph in the Air Almanac should be consulted.

1213. ABNORMAL REFRACTION

a. Generally speaking, abnormal refraction at sea is caused by an inversion of temperature in a layer of air, the variations in density thus produced causing light rays to be bent in excess of normal conditions.

b. The most favourable conditions for excess refraction, when the more fantastic forms of mirage and distortion take place, occur when a layer of warm air is in contact with cooler water. The air next to the surface of the sea is cooled, and consequently the upper layers are warmer than the lower, so instead of the usual decrease, there is an increase of temperature with height. Most refraction phenomena are formed at the boundary between this layer of cold, dense air at the surface of the sea, and the less dense warm air above. This condition is identical with that which is responsible for the formation of most sea fog, and the presence of fog is therefore an indication that excessive refraction can be expected.

c. Similar inversions may be caused by the presence of cold air over warm water. A marked difference between air and sea temperature is thus a guide to the presence of excessive refraction.

d. Although abnormal refraction is not restricted to particular geographical areas, certain regions are so situated with respect to general meteorological conditions as to be more favourable than others for the occurrence of abnormal refraction phenomena. In this respect the Arctic coasts are ideal because of the marked difference between sea and air temperatures. In the Arctic, excessive visibility, or some form of mirage, is often manifest when comparatively warm light winds blow over cold ice surfaces, or when cold winds blow over open water. A temperature, milder over open water than over a nearby ice-clad shore, also leads to refraction phenomena.

e. One form of abnormal refraction is "looming", which is the apparent raising of an object above the horizon. It is quite common at sea, especially in high and middle latitudes, and results in the appearance of distant objects which, in many instances, may actually be below the normal horizon at the time of observation.

f. There are two types of looming. On the one hand an object (island, iceberg, ship) is seemingly increased in elevation though not in size, on the other hand an object appears to be enlarged and brought much nearer to the observer.

g. The atmospheric condition that produces looming is one in which there is an abnormal decrease in the density of the air from the surface upward and hence a greater than normal downward curvature of the paths of light rays. The more rapidly the density decreases with elevation, the more unnatural and impressive the phenomenon becomes. Bulging, thinning, flattening or pointing may occur. Thus, a distant rounded peak might loom in its natural shape, appear with a perfectly flat summit, or with misshapen summit drawn much nearer to the observer than the base. Likewise, the appearance of the looming object from the masthead may differ from that at deck level.

h. Superior mirage is another form of abnormal refraction and is the apparent reflection from a mirror-like atmospheric condition where a pronounced temperature inversion exists at a distance of several feet above the surface. This inversion introduces an abnormal change in density resulting in extraordinary refraction. Its most frequent appearance is that of an inverted image above the object, but under suitable conditions a second mirage is seen erect, close above the inverted one. Sometimes the object is not observed directly and the inverted image, or the upper erect image of an object below the horizon, may be seen.

i. As with looming, the conditions needed for superior mirage is a warm layer of air existing over the sea at a suitable height, i.e., an inversion of temperature. The only difference between this and the condition necessary for looming is that for superior image there must be a more sudden change from cooler to warmer air at a certain height.

j. The observer in a ship near land usually sees mirage as an unnatural image of the coastline – single, double, or triple, or as an appearance of the coast much nearer to him, or farther from him than it actually is.

k. At sea, ships and icebergs are the mirage subjects usually sighted. Ocean fog is also associated with mirage, since the temperature and humidity variations which favour condensation of moisture as fog in the air, are factors in causing mirage. Mirage is not visible, of course, in dense fog, but mock fog, or the typical refraction band, is often seen under such conditions and may lead to the erroneous report of true fog.

l. Temperature inversions may cause abnormal dip of the horizon, seriously affecting the accuracy of sextant observations. The navigator should, therefore, be on guard against such possibility whenever there is a chance that a temperature inversion may exist.

1214. ECHO-SOUNDER

a. Charted soundings in many Arctic areas are sparse and often frustrate any estimate of a ship's position based solely on indicated depths.

b. In Arctic waters the echo-sounder is primarily a warning device. In poorly charted waters it is one of the navigator's most valuable aids and should be manned and operated continuously in dangerous waters. Uncharted rock pinnacles and shoal water can be encountered with alarming suddenness, and it is useless having vitally important information being displayed on a recording device if nobody is there to report it.

c. A ship's echo sounder will not always give a reading when ice is under the ship or when water beneath the ship is disturbed by propeller swirl when the engines are put astern, or by turbulence caused by ice floes being shoved around.

d. A ship having to proceed in uncharted coastal waters may minimize the risk of grounding by sending a boat away when ice conditions permit, equipped with a portable echo sounder, to scout ahead.

1215. LOGS

In the presence of ice, logs must be retracted or they will be wiped off.

1216. ELECTRONIC AIDS TO NAVIGATION

a. There are several electronic aids to navigation that are useful in one or more areas of the Arctic. Detailed information on availability of different aids to navigation systems is available in *H.O. Publication 117*. (See also Chapter 16 – Behaviour of Electronic and Sonic Emissions.)

(1) Consol/Consolan and Radio Direction Finder (RDF) Systems are azimuth measurement systems which can be used if available.

(2) Loran A and Loran C are pulse-time measurement systems that fix a ship's position by the reception and identification of pulses timed on a timed sequence from transmitting stations of known position. Loran A and Loran C coverage is illustrated in *H.O. Publication 117*. In the Arctic only skywaves are available, with consequent decrease in accuracy.

(3) The Omega Navigational System is a phase measurement system whose coverage will eventually be world-wide.

(4) The Navigational Satellite System is a world-wide navigational system. It is based on the principle of the "Doppler" effect, i.e., the shift of a transmitted frequency due to the relative motion between satellite and the shipboard receiver.

(5) Inertial Navigation Systems are passive, self-contained and cannot be affected by enemy action. Although these systems are highly sophisticated, they still accumulate a small error over a period of time and require recalibration using an external source. Commercial equipment used aboard high-speed long-range aircraft generates an average error of less than two miles per hour of travel.

(6) Acoustic Doppler Navigation Systems are not yet fully developed to the point where they can be used

effectively in waters deeper than a few hundred feet. These systems should help improve present dead-reckoning procedures and they also appear to be attractive for use in shallow waters or aboard deep submersibles operating near the ocean floor. Navigation accuracies are of the order of one percent of velocity and one percent of distance.

1217. RADAR AS A FIXING AID

a. Generally speaking, off-shore fixing by means of two or more radar ranges is recommended for use in Arctic waters. Such a method is quick, accurate and permits good fixing beyond visual ranges of land targets.

b. Suitably spaced fixes using radar ranges will reveal variable gyro compass errors and also the influence of unknown tidal streams. However, the precision of radar range fixing depends upon the correct selection of radar conspicuous points, and on their correct interpretation, from an accurately calibrated radar Plan Position Indicator (PPI).

c. Fixing solely by a radar range and bearing of a point of land, or by the use of radar or gyro bearings, is not recommended.

d. The following problems, peculiar to radar fixing in the Arctic, may be encountered:

(1) Difficulty in determining where the ice ends and the coastline begins when land is within the radar horizon. (A reduction in receiver gain should reduce the ice return.)

(2) Disagreement between ranges. (This may be caused by ranging errors, but is more probably the result of chart inaccuracies. The navigator should attempt to fix on the nearest land, and should not range on both sides of a channel or long inlet.)

(3) Uncertainty as to the height and, therefore, the detection range of most land masses. (The lack of topographical information on Arctic charts is steadily being overcome.)

e. The technique of radar ranging for fixing in the Arctic has the following advantages:

(1) It is available under all conditions of visibility and using all types of land targets, i.e., shorelines that have both low-lying and steep-to features.

(2) Where a coast is low and flat, positive identification of terrestrial targets for visual fixing purposes can be perplexing.

(3) Gyro errors are usually variable whereas a Plan Position Indicator Index Error for a given range scale can be ascertained and removed.

(4) Mirage effect in the presence of ice, especially on sunny days, can prevent positive identification of shore targets.

(5) If, as is often (but necessarily) the case, the centre of a "cocked hat" is taken as a ship's position, the small neat triangle produced by a radar range error (assuming there is one) gives a better fix than would be the case with an enormous "cocked hat" resulting from an unknown gyro error.

(6) At night the bearing method of fixing is impossible. Few shore objects are visible and lights for navigation purposes in Arctic waters are virtually non-existent.

(7) Visual fixing in conditions of fog and snow is impossible.

(8) By fixing at frequent intervals, a practical ship's track

can be derived, and adjusted, to avoid known shoals. The radar ranging technique is a rapid and simple method of ascertaining a ship's position and movement over the ground.

f. Radar should be calibrated whenever an opportunity occurs if it is to provide the navigator with accurate ranges. Range errors are not obvious at the lesser ranges, but become increasingly evident at ranges over ten miles.

g. Lack of topography on the chart in use may hinder identification of radar-conspicuous fixing marks; however, identification of radar-conspicuous portions of the coast may be assisted if topographic maps are consulted.

1218. RADAR AND SONAR FOR ICE DETECTION

a. *Radar*

(1) *Condition of the Equipment.* The importance of keeping radars operating at peak efficiency must be emphasized. In calm seas, the detection of bergy bits and growlers in time to avoid collision can be expected only if the equipment is performing perfectly.

(2) *State of the Sea.* As sea states increase so does the minimum size of iceberg that can be detected. In rough seas, bergs as tall as fifty feet cannot always be detected in the sea return. Only in smooth seas can radar be relied upon to pick up growlers.

(3) *Weather Conditions.* Meteorological conditions in some areas affect radar propagation in a manner which, under certain conditions of fog and rain, may reduce or obscure returns from ice just when they are most needed.

(4) *Operator Efficiency.* The best equipment can give maximum performance only in the hands of a well-trained and experienced operator. As the very least, a radar operator should be able to appreciate that his equipment is not performing as it was designed to do or that conditions are degrading its performance.

(5) Ice does not have the microwave reflection properties of metals and is therefore a much poorer radar reflector than ship-type targets.

(6) In moderately rough weather, the radar presentation may become momentarily blurred, but usually clears after one or two sweeps of the antenna.

(7) Targets may become lost due to the ducting effect of the beam caused by a decrease of moisture content which is often accompanied by a temperature inversion. Such ducting happens occasionally, but seldom to the extent that a target is completely lost. Another form of ducting has the opposite effect, i.e., bending the radar beam so that it follows the curvature of the earth, permitting detections at very great ranges.

(8) The blending of sea returns and returns from growlers poses a serious problem in ice detection, but one which can sometimes be overcome by an alert operator. In moderate seas, growlers alternately appear and disappear from the Plan Position Indicator but in approximately the same position at each sweep of the antenna. Sea returns, however, will fail to appear in the same relative position.

(9) Caution is necessary when ships are moving through pack ice in low visibility. Large iceberg returns can be distinguished from adjacent pack ice returns at ranges of 4,000 yards or more, but can be obscured by returns from pack ice at lesser ranges. What are actually shadows cast by large bergs can easily be mistaken for leads or open water. Anti-jamming controls are of some value in differentiating between pack ice and large bergs at

reduced ranges, but should not be relied upon.

(10) Floes up to six miles from a ship are well patterned on Plan Position Indicators, therefore radar can be of considerable assistance in showing up leads in the ice.

b. *Sonar*

(1) Experience in the Arctic indicates that icebergs can be detected more reliably by sonar listening than by sonar echo ranging. Bergs appear to produce a loud noise similar to high speed propellers in a ship, possibly caused by the release of air bubbles under pressure.

(2) Echo ranging has not proved to be dependable, often failing to indicate the presence of bergs at ranges where they were a hazard.

(3) Sonar fitted in icebreakers has proved to be of little value during summer Arctic operations, as the protective shield must be closed upon entering the ice to prevent certain damage to the sonar dome.

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CHAPTER 13

ARCTIC AVIATION

1301. INTRODUCTION

a. Cold weather flying operations call for a high degree of professional competence among aircrew plus careful inspections of aircraft, more faithful adherence to prescribed procedures and more frequent maintenance than is acceptable for comparable operations in more temperate climates. Experience has also shown that successful air operations in polar regions require considerably more preparation than air operations in other areas.

b. While routine tasks take longer because of difficulties posed by low temperatures, experience shows that aircraft and equipment can be maintained and serviced when exposed to ground temperatures as low as −50°C.

c. Technical procedures recommended, such as oil dilution, use of pre-heat, percent to which a jet engine should be accelerated before light-off, use of hot fuel priming, etc., MUST not be attempted without consulting the pilot's handbook and operating and servicing instructions for the type/model of aircraft involved.

1302. AIR NAVIGATION

a. Air navigation in high latitudes requires careful preparation for the following reasons:

(1) On most flights continual astronomical observations will be required for the determination of direction and for fixing.

(2) Electronic aids to navigation will be limited, as will meteorological information.

(3) Mapping is still inadequate in the more remote areas.

b. The air navigator will require a plotting chart of suitable scale, plus a set of topographical maps covering the area of the intended flight and all possible alternates. Mercator plotting charts can be used up to approximately 75°N depending upon the change of longitude involved. For flights north of 75°N, polar charts such as the Modified Lambert Conformal or the Polar Stereographic are recommended.

c. True direction (i.e., defining direction with reference to the local meridian) is not satisfactory for use in high latitudes because of the convergence of the meridians at the geographic pole. To overcome this, the system of Grid Direction has been developed. In this system one meridian is selected as a reference meridian and grid north is considered to be at an infinite distance along it. A number of lines are drawn parallel to the selected meridian to form the grid from which the system derives its name. Any straight line will cut each grid line at the same angle measured clockwise from grid north to the line, thus overcoming complications of rapidly converging meridians. For convenience, modern polar air plotting charts have such grid lines superimposed.

d. In areas where the magnetic compass is unreliable, the use of a freely suspended gyro has proved to be a statisfactory substitute. Basically, the technique involves determination of heading by astro-compass or sextant and maintenance of direction by gyro. A continuous record should be kept of gyro-drift, to correct the gyro.

e. The importance of astronomical navigation should be reflected in the thoroughness of pre-flight preparations. The air navigator must pay special attention to the availability of celestial bodies for fixing purposes, and to this end one of his most important functions will be to establish the duration and time of twilight, and to determine the availability of sun, moon and planet observations during the planned flight period.

f. A thorough pre-flight check of the air navigation equipment is essential. Before winter flights, the navigator should ensure that installed thermometers are capable of indicating temperatures as low as −60°C. It is advisable to have a radar altimeter installed especially if the aircraft is not equipped with other radar. A radar altimeter, together with a driftmeter and a stop-watch, provides a simple means of obtaining ground speeds in areas where accurate fixing is impossible.

g. When flying in the Arctic it is rarely possible to check the navigation watch against an accurately rated chronometer. However, radio time signals broadcast by WWV, Bureau of Standards, Washington, and CHU, Dominion Observatory, Ottawa, on a 24 hour basis, can provide an excellent means of obtaining accurate time.

h. For Arctic flying, it is essential that a navigator have a sound understanding of meteorology since both en route and area forecasts are sketchy and often lacking in detail. As synoptic charts are seldom available at high latitude bases, flights may have to be planned on weather information obtained by radio. Navigators should also acquire a knowledge of topography and ice conditions in their areas of operation.

i. Overall methods of navigation will depend upon the type of flight, type of aircraft, navigation aids available and weather conditions. An air navigator with a good background in dead reckoning and astronomical navigation, and who is proficient in the use of his equipment, should experience little difficulty when navigating in high latitudes.

1303. INSTRUMENTS

a. The formation of bubbles in magnetic compasses, usually caused by the failure of sealing compounds, can make them ineffective.

b. In general, instruments are capable of withstanding a cold environment since most of them are hermetically sealed. A possible exception to this could be the seals in pitot static systems which have a tendency to fail thus creating unacceptable leakage rates within the system.

c. Hysterisis error, which is present to some extent in most aircraft instruments, can become exceptionally large after an aircraft has been cold soaked. This phenomenon should be taken into consideration particularly during engine starts where part of the start sequence controlled by the operator depends on instrument indications.

d. Air-driven gyro instruments are unreliable below −20°C. Aircraft so fitted require efficient heating before take-off. Electrically-driven gyro instruments are much more reliable.

1304. ELECTRONIC EQUIPMENT

a. Ice can be a hazard on external antennae, causing breakages, changing antennae characteristics and reducing operating ranges.

b. Rubber-covered flexible cables become stiff below −10°C. Insulation becomes brittle with a tendency to crack and shatter rather than bend.

c. Slow-moving shafts and bearing surfaces will operate more satisfactorily if their surfaces are buffed and polished. They should not normally be lubricated at all.

d. Airborne electronic equipment has, in most cases, been designed to operate at temperatures below −40°C. A high standard of maintenance is required to prevent corrosion caused by moisture formed by rapid changes in temperature.

e. Static from electric discharges can cause interference, making radio signals unreadable and rendering radio compasses unreliable. Such static affects the lower frequencies which are the ones most commonly used in the Arctic. Some protection can be afforded by using polyethylene-covered antennae. Relief from static can be obtained by rotating the loop to the "maximum" position. This procedure can be used for range flying but must not be used for radio range let-downs.

1305. ELECTRICAL

a. Cold temperatures affect electrical components by stiffening and cracking insulation and plastic covers, and by stiffening switches, solenoids, relays and actuators. Metal fracture in components, such as switches and potentiometers, may also occur.

b. Electric motors may burn out when operated after a cold soak as a result of larger loads imposed by an increase in lubricant viscosity in the driven mechanisms.

c. The efficiency of batteries is reduced when exposed to cold. At −40°C the capacity of a typical storage battery is reduced to 25 percent of its capacity at −20°C. A cold battery cannot be charged as rapidly as one at normal ambient temperature. The charging rate at −20°C is one-sixth of that under ordinary conditions and for these reasons battery power should be conserved. Nickel-Cadmium batteries are affected to a lesser degree by cold weather and normally can be utilized after cold soaks in temperatures ranging down to at least −30°C.

d. Condensation causes corrosion of electrical equipment, particularly in relay contacts and switches. Spark plugs, magnetos, ignition harnesses and electrical leads are all susceptible to the ill-effects of condensation.

e. The removal and replacement of batteries in cold weather is a disagreeable chore, especially for a person encumbered by bulky clothing. As cables become stiff and drain tubes brittle, and as the batteries themselves are heavy, the adoption of quick-disconnect features is recommended.

1306. SERVICING AIRCRAFT IN COLD TEMPERATURES

a. The man-hours required to perform a maintenance task on an aircraft in cold weather is best determined by considering it to be a function of wind chill factor rather than temperature. Wind chill factor is defined as the rate of cooling in kilo-calories per square meter per hour of a body of neutral skin temperature of 33°C. Thus both wind and temperature affect the overall efficiency of technicians working in cold weather. (See Figure 17-II.)

b. Except for minor tasks, therefore, experience proves it is worthwhile erecting a shelter and using a ground heater. Temporary shelters of tarpaulins may be put up over a work area. Erecting a wind-break can reduce wind chill considerably even when no heat is available.

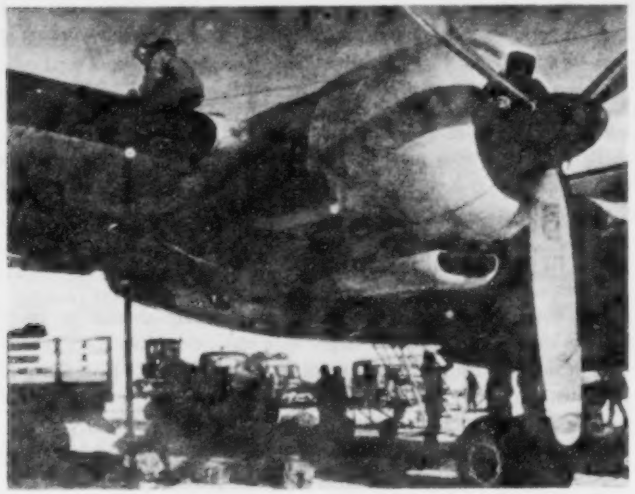
1307. REFUELLING

a. When refuelling at low temperatures, care should be taken because objects can become charged with static electricity more readily than at normal temperatures Explosive mixtures for JP4 exist down to a temperature of −23°C, and for Avgas down to a temperature of −43°C. All activities that could cause a build-up of static electricity, e.g., the sweeping of frost and snow from an aircraft, must be followed by complete dissipation of the static charge thus accumulated before fuelling is attempted.

b. Refuelling should be carried out as soon as possible after shut-down to prevent condensation. If refuelling takes place from an old cache of drummed fuel, pilots should subsequently be alert for rough engine operation and consequently higher cylinder operating temperatures, due to reduced octane rating, since stored fuel slowly deteriorates.

c. It is very important to discharge any accumulated static electricity immediately on landing and before any attempt is made to refuel.

d. Spilled fuel on the skin can result in quick freezing and severe frostbite of the affected area.



1308. OIL REPLENISHMENT

a. Oil replenishment is more of a problem in cold weather than it is in more temperate climates, especially for large aircraft. Oil barrels in storage must first be warmed so the oil can flow. Pumping is difficult because warmed oil cools and congeals very rapidly in the hose, making it impossible to force it through a hose. Experience favours supplying oil in five-gallon containers which can easily be handled, are quicker to heat and more easily stored.

1309. COLD STARTING PISTON ENGINES

a. Almost all types of piston engines can be started at temperatures as low as −30°C, and most will start, with assistance, at −40°C.

b. To start a piston engine the following conditions must be met:

(1) The propeller should first be pulled through by hand to ensure all moving parts are free and that there are no air or hydraulic locks.

(2) Adequate cranking power.

(3) A sufficiently hot spark, or ignition temperature or both.

(4) A combustible mixture in the cylinder.

NOTE: Of all the foregoing, a combustible mixture in the cylinder is the most difficult to provide at low temperatures.

c. Cranking rate depends upon the resistance to rotation of the internal mechanism of the engine, the type of starter used and the power supplied from the starter.

1310. ENGINE LUBRICATION

a. Increased engine drag in cold temperatures, while partially due to the differential contraction of the metals in the engine and engine-drive accessories, is due mainly to the increase in viscosity of the lubricating oil. A viscosity of about 35,000 SUS (Saybolt Universal Seconds) is generally considered to be the maximum desirable at start-up. Engine oil pressures become very high at low temperatures and often exceed the oil pressure indicator range for a few minutes during a start.

b. To achieve this viscosity at temperatures below 5°C, oil may be diluted with gasoline. This diluent is usually introduced into the oil just before the inlet to the engine lubricating pump. When introduced at this point the fuel and oil are mechanically mixed by the lubricating pump, thus preventing separation.

c. Undiluted oil in a tank can, because of its different density when compared to diluted oil, seep through the labyrinth of the hot well and into the oil tank outlets. This can result in undiluted oil congealing, and then restricting the inlet line to the oil pump, resulting in oil starvation on "start-up". A properly designed labyrinth, between the make-up oil and the hot well, will provide acceptable segregation of diluted and undiluted oil.

d. Replenishment of an oil tank should be carried out before oil dilution, or after the engine has been started, warmed up and the diluent boiled off. The former method is preferable, as the engine can be shut down after flight to allow the oil to cool to 60°C or below before diluting. Servicing crews must ensure that oil tank levels are checked after dilution.

e. Engines having no provision for oil dilution must have their oil tanks drained. Before "start-up" the oil tank is refilled with heated oil, engine and external lines are warmed using a ground heater, while also making use of an engine cover or tarpaulin to retain heat around the engine. Check for free flow of oil to the inlet of the oil sump in extreme conditions, and never attempt to start without a free flow of oil. Propellers should be pulled through four or five complete turns before engaging their starters to make sure all moving parts are free and that there are no air or hydraulic locks. If this cannot be done with ease, more preheating will be required. One procedure is to top up before dilution leaving sufficient space for diluents. If the oil quantities of the aircraft concerned are marginal for the length of flight involved, then it would be better to boil off the diluents and then top up with warmed oil.

1311. PISTON ENGINE SHUT-DOWN AND RE-STARTING

a. Before shut-down of a piston engine, dilution of the entire lubrication system must be carried out by introducing raw fuel into it to dilute the oil. By reducing its viscosity the oil will not congeal after the engine has cooled. To start, the engine must first be warmed so that it can be turned more easily. With the help of additional power, it is then turned over and primed to start combustion. Once started, it is warmed slowly under its own power, after which a fast idle must be completed to burn off the diluent gas to prevent dilution blow-out.

1312. EXTERNAL HEATING

a. The time required to pre-heat a piston engine depends on air temperature, engine size and heater output, wind over the engine, the efficiency of the engine cover and the amount of oil dilution. It usually takes thirty to sixty minutes.

b. The application of external heat is unnecessary in temperatures down to −17°C if the engine oil has been properly diluted.

c. With turbine-powered aircraft the need to pre-heat is greatly reduced.

1313. PROPELLERS

a. In aircraft fitted with Constant Speed Units (CSU) to control engine flow to the propeller, difficulty can be experienced with their operation just after take-off in cold temperatures due to high oil viscosity. By exercising CSU controls several times at the end of the dilution cycle, this trouble can be overcome because it introduces diluted oil into the CSU, into the associated oil lines, and into the propeller dome.

b. Trouble can be experienced while feathering and unfeathering in flight. Operating the feathering button during the last few seconds of the dilution cycle, and operating the unfeathering control after the RPM have dropped off by about 400, can make feathering possible after take-off.

c. A solution to this problem would be to introduce a dilution line into the feathering line inlet, controlled by a solenoid wired to the feathering and unfeathering control. Oil in the feathering lines, and in the propeller dome, can be kept at 25 percent dilution, and feathering and unfeathering in flight made possible at −40°C.

1314. COLD STARTING JET ENGINES

a. Jet engines are easier to start than reciprocating engines, successful starts having been accomplished in temperatures as low as −47°C without the application of heat. To start a jet engine it must first be accelerated by the starter to a starting RPM in the vicinity of 15 to 18 percent. An electrical starter, capable of turning the engine up to the required RPM, requires a high output energizer to furnish the necessary power. In extremely cold weather the engine oil sumps may require heating.

b. Air turbine starters, driven by air supplied from a gas turbine compressor, will accelerate jet engines to idling RPM in half the time required by an electric start. A gas turbine starting unit is also a convenient source of heat.

c. Cartridge-burning starters can be used on engines fitted with a cartridge receptacle. This type of starter requires no ground power unit and also brings an engine up to starting RPM more rapidly than an electric starter.

1315. LOW TEMPERATURE FUEL COMBUSTION

a. It is difficult to provide a combustible mixture at low temperatures in an aircraft engine without using elaborate equipment. To overcome lack of vapour pressure, priming at pressures of 60 - 75 pounds per square inch can induce more rapid fuel vapourization through finer atomization of the fuel. The priming fuel flow for cold starting must be sufficient to keep the engine running at idling RPM, on 'prime' alone, until it will run smoothly on the carburettor.

b. Additional aids to cold weather starting are:

(1) The use of wrap-around electric heaters on induction manifolds.

(2) The use of highly volatile fuel for priming.

(3) Hot fuel priming.

c. Whether priming fuel is more effective when applied before cranking, or during cranking, varies with each type of engine. As temperatures drop, more prime is required to obtain a combustible mixture. The most effective moment to prime, for most engines, appears to be during the cranking run when the blower is assisting in atomizing and evaporating the fuel. Since priming fuel will not evaporate rapidly when it is cold, the risk of fire from over-priming is more serious. Judicious use of the throttle, as appropriate to the particular engine operating procedures, is essential to successful cold starting.

d. When attempts to start an engine, without first applying heat, have failed it is obviously desirable to heat it. Heat from a ground heater is retained around the engine by a cover or tarpaulin, while some of the heat should also be directed to the cylinders, carburettor and the accessory section. Sufficient heat should be directed to the engine accessories to reduce the drag forces set up by congealed oil. Failure to do this can result in twisted or sheared accessory drives, or a reduction in RPM sufficient to prevent a start. Changing to lighter lubricant can sometimes make the difference between a mechanical failure, a start failure or success.

1316. CONDENSATION

a. In some engines, oil circulation fails because water accumulates and freezes in the oil lines or oil tank sump. Oil coolers can be split by water freezing in them. As much as a gallon of water has been drained from the oil tanks of an engine after prolonged ground running at a temperature below −30°C. This can be prevented by running engines at high power, just before shut-down, to raise oil temperatures to the permissible maximum.

b. In some aircraft engines, too much dilution of fuel vapours can result in spewing from vents as they boil off rapidly at higher powers. Vents must be large enough to handle the volume of gases to be vented, and be positioned so as to be in view of the pilot. They must also be positioned clear of exhaust outlets which could ignite such highly volatile fumes.

c. Some installations may require heating of vent outlets to prevent freezing of water vapour and consequent plugging with ice. This is a common occurrence and all vents must be checked for ice accumulation.

d. Ensure that all engine orifices are well covered on the ground to prevent ingestion of snow which will melt and subsequently freeze.

1317. AIRFRAMES

a. Airframe lubrication has been a problem, but the development of low temperature greases and oils has reduced this to manageable proportions.

b. Differential contraction can result in skin buckling, in loss of cable tension and in the cracking of perspex and other plastic panels in airframes. Skin wrinkles can also occur, especially near heated ducts.

c. Loss of tension in control cables can be serious in some types of aircraft. Drops in tension have been experienced, ranging from 100 pounds to less than 30 on control cables and from 25 pounds to nil on trim control cables.

d. Perspex panels and canopies tend to crack in cold weather unless properly formed, properly annealed to remove residual stresses, and with attachment holes elongated to permit relative movement. Cockpit canopies should be checked for cracks before flight, as they may disintegrate in the air.

e. Hydraulic leaks persist as a serious cold weather problem. Most are caused by:

(1) Differential contraction at unions.

(2) Hardening of sealing glands.

(3) Ice formation of jack rams resulting in damage to glands.

f. Without using a shelter there is no guaranteed method of preventing ice, frost and snow from accumulating on aircraft surfaces.

Covers are useful against loose snow, but slushy snow and freezing rain can cause them to freeze to the surfaces they are supposed to protect, making them extremely difficult to remove.

g. Intensely low temperatures, as would be experienced during an Arctic winter, are generally associated with clear skies and rapid heat radiation. Temperatures dip rapidly at night resulting in high relative humidity and the formation of hoar frost. This form of frost can form on aircraft, despite the presence of covers, and cannot easily be removed.

h. Dry snow can usually be brushed off, but ice and wet snow, which have been permitted to freeze on aircraft surfaces, are extremely difficult to remove. Alcohol, glycol and other fluids have all been tried but most of them are ineffective below −25°C, and they are also very expensive. Check control surface moisture drain holes for ice blockage prior to flight.

i. Portable heaters can be used but the melt water thus formed will probably run to a lower part of the aircraft and re-freeze. Ice on an aircraft can also be removed by parking the machine in the exhaust stream of a jet aircraft, though this can be an extremely hazardous procedure.

j. Airframe problems associated with slushy snow and freezing rain, during transition temperatures close to 0°C, are as troublesome as those experienced at much lower temperatures. Slushy snow entering parts of an aircraft, where it can freeze overnight or during flight, can cause frozen brakes, undercarriage frozen "up" or "down", flaps frozen "up", or plugged vent lines. After take-off from slush, the landing gear and flaps should be operated several times to prevent freezing in the "up" position. Do not apply parking brakes while brakes are still warm.

k. If tires freeze to the ground or deck they can be freed by using external heat from ground heaters. In an emergency they can also be freed by over-inflation (within the safety limits of the tire) provided that precautions are taken by people standing nearby. Such freezing can sometimes be prevented by running wheels onto pieces of plywood when parking aircraft. The freezing of aircraft skis should be prevented by parking such aircraft with its skis resting on boards or other suitable material

NOTE: Tire air pressures drop and tire leak rates increase with a decrease in temperature.

l. Vinyl-coated nylon has given good service as an aircraft cover material and has been the easiest to handle. Fasteners must, however, be large and manageable.

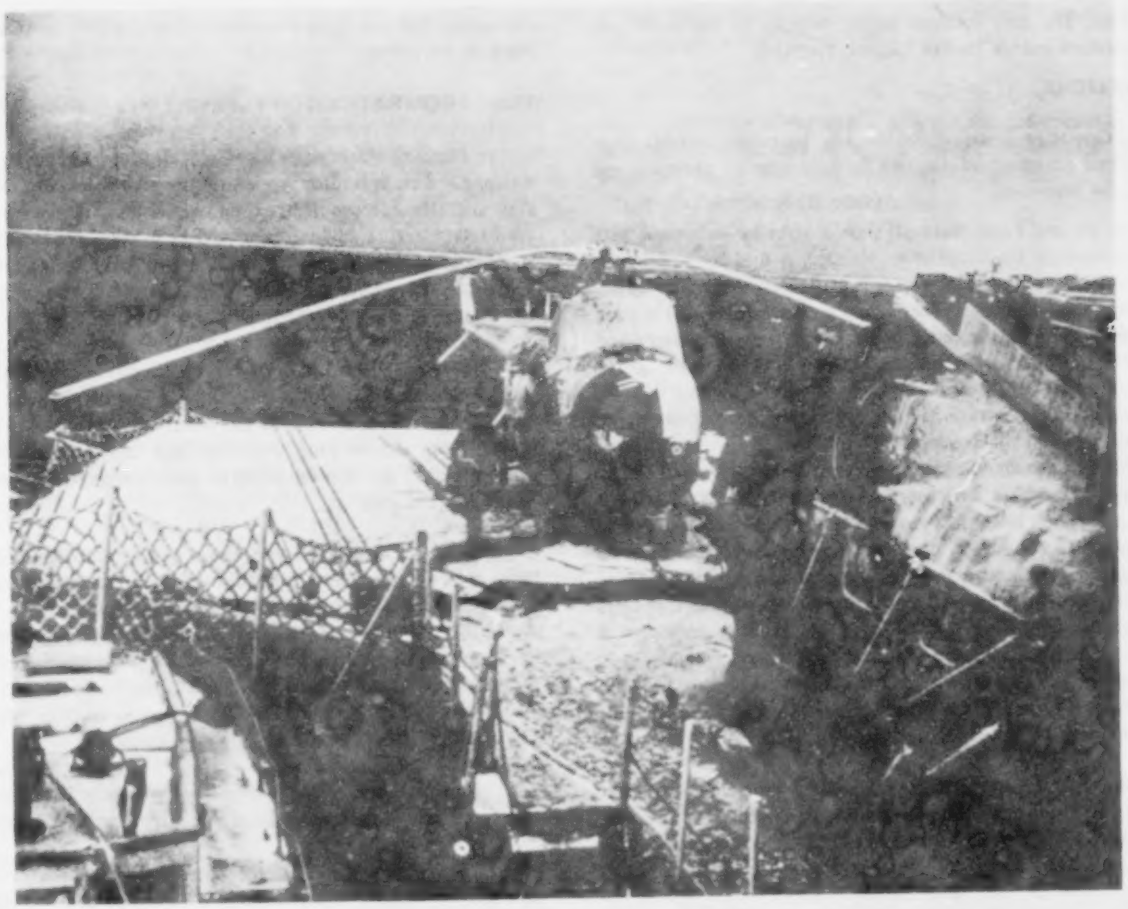
m. Covers should be clearly marked with coloured identification points, so they can be positioned on an aircraft quickly and easily. Blown snow can drift through the smallest chink, making it imperative to blank off all openings.

n. Drain water systems prior to cold soaking aircraft.

1318. FLIGHT OPERATIONS

a. Unfavourable weather restricts flying in any area. In the Arctic it is especially necessary to be familiar with conditions affecting flight operations, for storms can occur there with little warning. Icing conditions almost always exist, and as long as de-icing equipment remains only partially effective, icing can be overcome only by avoiding those altitudes at which it is most likely to occur. Fogs and low cloud are also natural products of polar areas in summer. At times dry surface snow raised by high winds tends to obscure the ground and the horizon, reducing visibility and obliterating all references to surface and sky ("whiteout"). Any of these conditions makes flying dangerous, but a thorough knowledge of the hazards involved coupled with observance of proper precautions will help to reduce the risk.

b. In the matter of maintenance, close attention to detail is necessary because of the strain placed on aircraft by low temperatures and because of the fatal consequences likely to follow mechanical or material failure in flight. Low temperatures increase the difficulty of performing routine tasks and also increase the time required to



complete them. The time involved largely depends on the protection afforded personnel and the kind of facilities provided.

1319. PREFLIGHT

a. The Operating Instructions for any particular aircraft type provide the best source of information for cold weather operation and must always be consulted.

b. *Snow, Ice and Frost.* Take-off should never be attempted with snow, ice or frost on the wings or empennage. A thin layer of ice, or snow which rapidly compacts into ice, will cause loss of lift and stalling. Hoar frost and snow should be swept from surfaces with a stiff broom. All accumulations of snow must be removed from the wings and fuselage.

c. *Ice Removal.* To remove ice from aircraft parked outside, apply isopropyl alcohol if it is available. To remove ice from hangared aircraft, sufficient heat should be applied to loosen the ice particles so that they can be removed with a brush. It is best not to melt the ice completely as water is likely to penetrate control surface bearings and freeze. Landing gear, bomb-bay doors and flap operating gear must be freed of ice and snow. Remove snow from the carburettor intake. Clean off antennae using a light pole. Operate all ailerons, elevators, rudders and trim tabs through several complete cycles and, if resistance is excessive, a careful investigation must be made. Experience in extremely low temperatures indicates that hydraulic systems are a major problem because of frequent shock-shrinking of seals resulting in the collapse of oleos and pistons.

d. *Shock Struts.* Wipe the shock strut piston tubes and oleos clear of all snow, ice or dirt with a cloth soaked in the fluid used in the strut oleo. Kerosene can be used if necessary. Follow by lubrication with hydraulic fluid. This is also a post-flight procedure. Clean piston rods of actuating cylinders in the same manner. Shock struts should be carefully examined for hydraulic leaks and proper inflation. Check for the proper distance from the lower end of the cylinder to the inflation mark on the piston.

1320. PREPARATION FOR FLIGHT

a. *Planning.* Take care to learn the special distress, bail-out, ditching and crash-landing procedures. Be sure you know; do not guess. Plan and schedule pre-flight ground activities. Arrange the periods of pre-heating so that all equipment will be inspected, warmed, ready and running at start-up or take-off. While pre-heating is taking place, ice and snow should be removed, inspections and operational checks made and electronic equipment warmed up.

b. *Personal Care.* Load survival equipment and rations. Dress for the worst conditions, not the best. Wear clothing appropriate to the area of operations. Beware of the effect of cold metal on skin. Wear gloves. Keep out of prop wash–its blast can cause severe frostbite. Spilled fuel on the skin can result in quick freezing and severe frostbite of the affected area.

c. *Weather.* Obtain the very latest weather information. Know the limits of your aircraft and its instruments in Arctic conditions.

d. *Warm-Up.* Warm up engines thoroughly. Do not turn on electrically heated suits, or other non-essential electric equipment, until the generator shows output.

1321. HEATING

a. There are three types of heating equipment in service: combustion type heaters, electrical heaters and compressor bleed air heaters.

b. *Combustion Type Heaters.* These receive fuel from the aircraft's fuel supply, burn it within a sealed combustion chamber and exhaust the products of combustion overboard. Clean ram air flows over the complete them. The time involved largely depends on the protection afforded personnel and the kind of facilities provided.

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b. *Combustion Type Heaters.* These receive fuel from the aircraft's fuel supply, burn it within a sealed combustion chamber and exhaust the products of combustion overboard. Clean ram air flows over the combustion chamber, is heated by it and is then ducted to the cabin. The pilot may operate the heater at full or at half capacity.

c. *Electrical Resistance Type Heaters.* These, together with heating blankets, are used whenever spot heating is desired. In some instances electrical resistance heaters, in conjunction with blowing units, are used for windshield defogging/defrosting.

d. *Compressor Bleed Air Heating.* This type is used in turbo-jet aircraft and in all pressurized aircraft for cabin heating, and for windshield defogging/defrosting purposes. Temperature is thermostatically controlled to the desired value by mixing cooled air with hot air direct from the compressor in the desired proportion. At low ambient temperatures this source of heat is usually ineffective in "pure-jet" gas turbine engines running at an idle RPM. This presents a windscreen defogging/de-icing and cabin conditioning problem on the ground during taxiing, which may require 10 to 15 minutes on many airports. Turbo-prop gas turbines do not have this problem since they idle at a high RPM.

1322. ANTI-ICING

a. In general, icing conditions occur between – 18°C and 0°C, and at altitudes extending from sea level to 20,000 ft. (6,100 m.). In flight, ice forms on the leading edge of wings, empennage and other aircraft surfaces. While moored under conditions of freezing rain, ice forms on all the upper surfaces of an aircraft. In both instances this ice must be removed completely before take-off. The formation of ice on wings, empennage, radomes and the propellers adversely affects aircraft performance because of the added weight and the change in shape of the airfoil section.

b. *Thermal Anti-icing.* By heating critical surfaces, droplets of water impinging on the affected parts are prevented from freezing. If sufficient heat is available to evaporate all the droplets, and maintain the leading edge surfaces in dry condition, water may move aft on the airfoil and refreeze to form what is called "run-back", adversely affecting airfoil lift characteristics.

c. *Anti-icing Compounds.* Compounds are available to delay or prevent the accumulation of ice on aircraft surfaces. One of these materials which has been found to be satisfactory is an inhibited thickened solution of lithium chloride.

1323. DE-ICING

a. *Mechanical.* Boots of rubber type material are cemented to critical surfaces. Elongated cells in the boots, extending chordwise so as not to affect airflow over the surfaces adversely, are alternately inflated and deflated by air pressure. Flexing of the boot dislodges the ice which is then removed by the air stream. As icing conditions increase in intensity, the cells of the de-icing boots are pulsated at a faster rate.

b. *Thermal.* Critical surfaces may be de-iced thermally by periodically melting the ice on the affected areas. In this case only the layer of ice in contact with the aircraft surface is melted. Removal of this ice is accomplished by aerodynamic drag.

1324. ROTARY WING AIRCRAFT OPERATION

a. Cold weather operation of helicopters should be in accordance with the applicable NATOPS manual for each individual aircraft.

b. *Whiteouts.* A "whiteout" condition is usually indicated by a complete overcast and an indistinct or non-existent horizon. A complete lack of depth perception may be experienced, resulting in an extremely hazardous flight condition. Helicopters should not be flown unless visual contact with the surface is assured. Should instrument flight conditions be encountered or observed the pilot should turn back or land before losing visual contact with the surface. "Greyout" conditions are usually forerunners of whiteouts. Complete overcasts, hazy horizon, loss of shadow, and reduction in depth perception are conditions that normally exist. The pilot should not proceed on a flight when these conditions are encountered; he should return to or remain at the base.

c. *Landings*

(1) *Whiteout and/or Low Visibility Procedure.* If a pilot must land in whiteout conditions, he should use all information available such as the nature of the terrain, wind conditions, information from ground parties that may be in the area, use of several smoke grenades, Navaids, GCA, etc., if available. Landings should be made into the wind at as low an air speed as possible (ground speed must be at minimum). Rate of descent should be less than 200ft. (60 m.) per minute. (NOTE: Radio altimeters may be as much as 75 - 100 ft. (22-30 m.) in error.) When contact with the surface is made, aft cyclic should be applied to stop forward motion and prevent the helicopter from nosing over. The landing must be made on instruments. Pilots should not attempt to estimate altitude visually and fly contact to a landing; it cannot be done safely.

(2) *Landing in Snow Covered Areas.* As the final phase of the approach ends and a hover is commenced, huge clouds of blowing snow may envelop the aircraft reducing visibility to zero. For this reason, if possible, a zero speed, no hover landing should be made. If a hover is unavoidable, however, a landing can be accomplished safely in most areas by holding an external reference point close to the aircraft to stop all relative motion. Crevasses are another hazard in snow surface landings. When landing in a known or suspected crevasse area, the helicopter should be kept light on the wheels/skids until the crewman can conduct a close visual inspection of the surface from the cabin. If the area appears safe, the pilot may then slowly reduce collective to a minimum while maintaining sufficient rotor RPM to effect an immediate take-off if the aircraft should start to tilt. Should it become necessary to land in a known crevassed area, personnel debarking from the aircraft should wear a safety line until the area is probed and safe walking areas marked.

1325. FIXED WING SKI OPERATION

a. Cold weather operation of fixed-wing aircraft should be in accordance with the applicable NATOPS manual for each individual aircraft.

b. *Snow Characteristics.* Ski aircraft operations in North America are usually carried out from snow-covered frozen lakes which provide relatively level take-off and landing areas. In Arctic regions, snow fields provide the operating bases for ski aircraft. Snow conditions on frozen lakes vary considerably depending on ambient temperature, solar radiation, and wind velocity, but three main conditions of snow are encountered: cold dry snow, slushy snow and "sticky" snow. It is possible to find these three types of snow simultaneously on the same lake provided that:

(1) Ambient temperature is below freezing;

(2) some areas are sheltered from the sun and exposed to

the wind; and

(3) other areas are sheltered from the wind and exposed to the sun.

c. *Cold Dry Snow.* Cold, dry snow is generally encountered at temperatures below −10°C with surface winds. Frictional resistance to sliding on cold dry snow increases with decreasing temperatures; in general, the lower the temperature the more adverse the snow condition for ski operation. However, on dry snow, since the frictional drag on the skis decreases with increasing velocity, take-off can be made without difficulty when continued acceleration is possible.

d. *"Sticky" Snow.* "Sticky" snow results from solar radiation which, even at freezing temperatures, causes particles of snow to melt and distribute water droplets throughout the upper layer of snow. A "sticky" snow condition is most likely to occur when the snow is fresh and fine-grained. As the snow becomes older and more coarsely crystalline, particularly after repeated thawing and refreezing, it becomes less subject to the "sticky" condition. While limited "sticky" areas can develop at below freezing temperatures, the snow usually becomes "sticky" over the entire surface of a lake when the ambient air temperature rises above the melting point. "Sticky" snow offers the highest viscous drag on the ski bottoms when the snow crystals are small and complex in construction. When snow contains water, the frictional drag on skis increases with increasing sliding velocity; in an extreme condition the airplane may reach a point at which the drag equals the available thrust before take-off speed has been reached.

e. *Slushy Snow.* The condition known as "slush" is essentially a deep snow condition which results when water flows into the base of the snow cover. This water is prevented from freezing by the insulation of the soft surface snow, and the slush condition may persist for extended periods even during extremely cold weather. On lakes the water usually flows up through cracks in the ice when the snow load exceeds the buoyancy of the supporting ice. When snowfall occurs early in the winter, the insulating action of the snow cover tends to prevent development of thick ice, and subsequent heavy snowfalls frequently result in slush. In late winter, when air temperature rises above the melting point during the day, slush usually forms on lakes with a heavy snow cover even with a thick ice base. Slush also may be caused in isolated instances by a run-off from the shore caused by solar radiation. Lakes, in which there are fluctuations of water level usually due to power dams, may exhibit slush at any time during the winter even though snowfall has not been heavy. Similarly, rivers and lakes through which there is an appreciable flow of water frequently exhibit spots where ice has been melted by the action of the current, and slush usually exists around these openings. Slush seldom exists over a whole lake surface; it is most frequently located near the shore where the snow load is heaviest. There is usually a considerable increase in the mechanical resistance to sliding when the skis encounter slush caused by the increase in ski penetration. While slush is not a serious problem, it results in some loss of airplane performance and should be avoided when alternate areas are available.

f. *Take-Off*

(1) *Drag Characteristics.* The sliding characteristics of skis on snow are different from the rolling characteristics of wheels. On a smooth, hard runway the rolling resistance of wheels is small and, to effect take-off with a minimum ground run, the aerodynamic forces operating on the airplane are the principal consideration. The sliding resistance of skis is frequently appreciable, depending on the applied load, the sliding velocity and the condition of the snow. Generally, drag on skis decreases with decreasing load. Thus, it is frequently possible to effect a net gain in performance by accepting an increase in aerodynamic drag to develop lift in order to reduce the load on the skis. On dry snow the

frictional drag on the skis decreases with increasing velocity and, with continued acceleration, take-off can usually be made without difficulty. On "sticky" snow the frictional drag does not decrease with increasing velocity to the same extent as on dry snow, and if the mechanical resistance to sliding is high, acceleration decreases as the sliding velocity increases. In this situation, it is generally advisable to increase the aerodynamic lift through use of the flaps and control of the airplane attitude, and to become airborne at minimum speed. Assuming the airplane is moving, the next consideration is the best procedure to follow in order to become airborne with a minimum ground run.

(2) On wheels, the rolling resistance on a hard surface is relatively independent of the load; on skis, particularly at low velocities, the resistance is increased considerably as the load increases. As the wings develop lift, they reduce the load and decrease the drag on the skis, but at the same time the aerodynamic drag is increased. The determination of the optimum airplane attitude and flap setting as a function of velocity which will give the lowest combined aerodynamic drag and sliding resistance, is a matter of experienced judgment. The airplane attitude should be positive but not to the extent that the wings are stalled out.

(3) Except on ice or dry snow which is not significantly deformed by the skis, a longer ground run is required for take-off, though the difference is not as great as might be imagined. For one thing, skis are never used at temperatures much above the freezing point and, except in the case of "sticky" snow, the high drag on skis is encountered only during the low velocity period during the take-off run. The time required to attain 10 - 15 kts. may be significantly greater than when on wheels, but the distance covered during this time is not great due to the low velocity. When operating from a prepared runway or permanent bases, the snow is always packed and the performance on skis compares favourably with that on wheels.

(4) Aside from selection of the best take-off area and control over the aerodynamic lift, there is little a pilot can do to affect the performance achieved during the take-off run, but exercise of considerable judgement is required to arrive at the best compromise of aerodynamic drag versus sliding resistance where take-off is critical.

g. *Landing.* When landing area conditions are not known, the most important consideration for ski landings on lakes is as exact an evaluation as possible of snow surface conditions and ice thickness.

(1) *Depth Perception.* When operating on snow surfaces, depth perception is frequently impaired, and under such conditions landings must be made with caution. Depth perception usually is poorest on hazy days when diffused light does not cast any shadows on the snow surface. Atmospheric conditions have an important effect on the visibility of the snow surface. Ice particles in the upper atmosphere frequently diffuse the sunlight to the extent that even major irregularities on the surface of the snow do not cast an observable shadow. This atmospheric condition, doubly hazardous since it is always accompanied by a loss in depth perception, is known as "whiteout" and point-to-point visibility is frequently very good up to fairly high altitudes at such a time. A

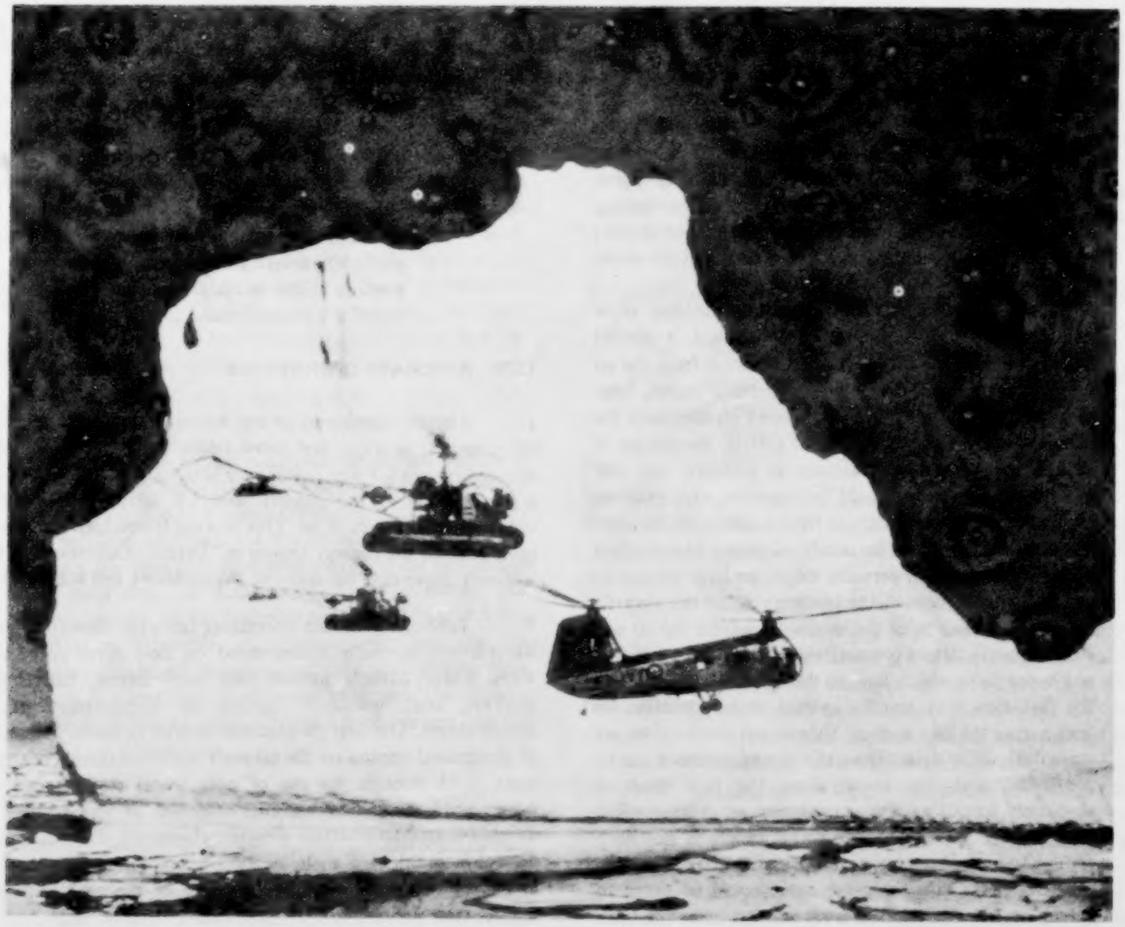
"whiteout" condition can be recognized by the grey or white colour of the sky. Blowing snow, also, can conceal the nature of a lake surface as well as its exact altitude; this presents a condition similar to ground fog and it should be avoided whenever possible. Under conditions which cause impaired depth perception, it should be assumed that the snow surface is considerably higher than it appears. For ski landings under these conditions, let down on the final approach at a safe rate of descent (200 ft./60 m. per minute) until the skis touch the snow.

(2) *Surface Hazards.* Even with apparently suitable snow conditions, before a landing is attempted, a careful examination of the surface should be made from the air to detect pressure ridges and concealed rocks, logs, blocks of ice and hidden trails. When operating near the shore where snow is deepest and softest, the danger of striking submerged obstructions is greatest, and any mounds in the snow should be regarded with extreme suspicion as they are likely to have a hard core. Pressure ridges in the ice occur on nearly all except the smallest lakes, and even small pressure ridges are large enough to cause major damage to the landing gear of the aircraft. Careful examination of the landing area from the air will almost always detect pressure ridges due to their height and sharp faces which tend to throw a good shadow and the fact that they usually extend in long continuous lines across the lake surface. Submerged obstructions are more difficult to detect from the air and, unless it can be confirmed that the snow along the lake shore is absolutely free of suspicious prominences, more exposed areas of the lake where the snow usually is not deep enough to hide obstructions may provide a better landing site. Before landing, extreme care should be taken to detect any signs of roads or trails across a lake. The trails may be paths used by trappers or animals, commercial fishermen or woodcutters, sled trains, or even airplane ski tracks. They usually are dangerous only when the snow is deep and soft, and the trail has been used repeatedly between snows. As a result of repeated traffic packing down the snow and fresh snowfall filling the track, a hard ridge of snow is built up. The top edge of the ridge after a fresh snow may be flush with the adjacent soft snow. An accidental encounter with a trail of this nature can result in severe damage to landing gear. Whenever possible, the location of trails and pressure ridges should be fixed in the mind or on a map before a landing is made.

1326. AIRCRAFT OPERATIONS

a. Aircraft operations in the Arctic normally are conducted from ice runways, skiways, and snow fields. Ice runways usually are constructed on sea ice which will vary in thickness up to 7 ft. (2m.). Snow is removed from the runway area by scraping to permit wheeled operations on the bare ice. This process leaves high banks of snow on both sides of the runway known as "Berms". Conditions of the runway will vary depending on ambient temperatures and solar radiation.

b. *Take-off.* Wheeled operations from ice runways present several hazards not normally encountered on ice-covered paved-surface runways. These hazards include high snow Berms, barrels for runway markers, and "pot-holes" caused by higher-than-normal ambient temperatures. The first two hazards require extremely close monitoring of directional control on the take-off roll. Directional control should be maintained through the use of nose wheel steering and differential power until the rudder becomes effective, at which point the rudder should be used to maintain directional control. Runway pot-holes will present a problem if their location is unknown. These pot-holes can be located only by personnel walking or driving down the runway before taxi or take-off. If pot-holes are quite large and deep, the runway should not be used. On ski take-off from open snow fields, cold



dry snow, "sticky" snow and "sastrugi" may be encountered. Normally, JATO should be used for open-snow take-offs. A skiway may be "packed" to assist take-off.

c. *Landings.* When landing area conditions are not known, the most important consideration for ski landings in the Arctic is an exact evaluation of the snow surface conditions.

(1) *Selection of Landing Area.* When depth perception is not impaired by adverse conditions, it is possible by observation from the air to identify crevassed areas, smooth snow, and areas of "sastrugi". Obviously crevassed areas should not be considered for a landing site because of their depth and roughness. Crevasses may be compared to a series of large canyons such as may be found in the western United States. Crevasses occasionally are covered with snow bridges which will not support an airplane; however, these areas are visible from the air. "Sastrugi" will vary because of wind conditions, ambient temperatures and new snow falls. Landings should normally be made parallel to, and between, the primary direction. Second "sastrugi" is a smaller drift area caused by a light wind from the direction of the prevailing wind. Ski landings normally will not be attempted in unknown areas in the Arctic until reconnaissance of the area has been completed.

(2) Open field landings in the Arctic are extremely hazardous and require professional preparation and execution. Landing sites should be selected from suitable locations on ice shelves or large polar plateau snow areas. Landing attempts should not be made on glaciers, glacier origin points, glacier terminals, or dry land areas. Before any open field landing, a comprehensive study and pre-flight analysis of the proposed landing area and its attending problems should be made. Once this study is completed, an area reconnaissance flight of the intended landing site shall be made. This flight should carry on board the following items:

(a) Best available maps, photos and other briefing materials.

(b) Items required for marking the landing site if a landing is made. (Minimum cargo should be carried and should be placed to provide the optimum centre of gravity for landing.) Runway markers should be of non-reflecting material.

(c) Minimum fuel load with sufficient reserves to allow the aircraft to:

1. Spend two hours on deck with all engines operating.

2. Return to base.

3. Have normal required reserve fuel after arrival at base.

(3) A minimum crew (only passengers vitally concerned with the location and condition of the landing site under investigation) should be carried.

(4) Smoke grenades should be used to determine wind directions for all landings.

(5) Markers and radar reflectors will be used, if a landing is completed, to designate approved areas that do not have a nearby landmark or terrain features for locating the site at a later date.

(6) All flight instruments must be working accurately and under no circumstance should a landing be attempted or terrain reconnoitered without using a radio altimeter and cross-checking all pressure altimeters aboard.

(7) When it has been ascertained that local weather conditions, surface definitions and visibility are good, the reconnaissance flight should then carefully explore the entire area involved for snow condition, hidden hazards and crevasses. The minimum altitude should be 500 ft. (150 m.) above the terrain. Extreme caution must be exercised when flying in such an area at low altitudes to allow sufficient safety margin for clearing all obstacles.

(8) Once the area has been investigated thoroughly and all indications are that the area is satisfactory for a landing probe, make preparations for a touch-and-go landing. (If a doubt remains at this time, a landing should not be considered. Find a new area or return to base.)

(9) If conditions are found to be satisfactory on the touch-and-go, a full stop landing may be made on the next pass and marking procedures completed for later use.

CHAPTER 14

SUBMARINE AND ANTI-SUBMARINE OPERATIONS

SECTION I – SUBMARINE OPERATIONS

1401. MATERIAL READINESS

a. A submarine destined for under-ice operations must rely completely on her machinery and equipment. Over-sophisticated gear that sacrifices reliability, repairability and material performance has no place in the Arctic.

b. During Arctic operations various problems peculiar to submarines may be encountered. Some of these include:

(1) Icing of the main induction and snorkel valves causing these valves to jam open. Icing of the main ballast tank vent valve linkages, rendering them inoperative and making diving impossible. This latter condition can only be avoided by frequent cycling of these valves, or by diving often enough to keep them ice-free.

(2) Icing of the submarine superstructure which can produce a difficult and sometimes dangerous stability problem.

(3) A submarine's bridge is very exposed and close to the sea. It becomes untenable most of the time in very cold, rough weather.

(4) Even small pieces of ice can damage snorkel masts, antennae and periscope.

(5) Under certain atmospheric conditions, heated snorkel exhaust gases can create a vapour trail which can betray the presence of a submarine.

c. The fairwater must be reinforced and should be smooth, curved and clean-swept to permit surfacing in ice cluttered leads and amongst brash, or to break through new ice which can form at any time of the year. All "through the hull" equipment (radar, periscopes, antennae, snorkel) should retract so that they are flush with the hull and have protective covers.

d. Upward-looking sonars, upward-beamed televisions and echo sounders are required for:

(1) Evaluating the type, distribution and thickness of the ice canopy.

(2) Making ascents into leads and polynyas.

(3) Locating sheets of new and young ice which form in leads and polynyas during winter operations.

e. Accurate high latitude navigation systems are necessary, the most important parts of which are accurate and reliable compasses. Submarines fitted with Ship's Inertial Navigation Systems (SINS) are best equipped to cope with the problems of high latitude navigation.

f. Periscopes, snorkel-head valves and antenna insulators must be equipped with de-icing arrangements. Periscope exposures above the surface should be brief because cold air may cool periscope heads sufficiently for internal moving parts to freeze.

g. Accurate injection temperatures can be an aid in predicting ice conditions and in navigation. Normally, sea water temperatures can be obtained from the main motor circulating water thermometer.

h. To lessen the risk of ice damage to propellers, they should be made of a special alloy, such as nickel-aluminum-bronze. A submarine should have either two propeller shafts or a secondary propulsion system available.

1402. UNDER-ICE PROCEDURES

a. *Depth.* Sea ice thickness varies but does not appear to exceed 12 ft. (4m.) except when heavy ridging occurs. Icebergs, particularly the block shaped type with precipitous sides, having five times as much ice submerged as exposed, pose a threat in those areas where bergs abound. Cruising depths must, therefore, allow for an adequate safety margin.

b. *Speeds.* In diesel battery-powered submarines the need to conserve battery power makes it necessary to use the most efficient speed for each class. No such submarine should penetrate further under the ice than forty percent of her battery capacity will allow. If, by that time, no lead is found in which to surface and recharge batteries, the submarine should return to her point of entry. Submarines with nuclear propulsion are under no such restriction and can roam at will under the ice.

c. *Deep Submergence and Angles.* Submarines must be rigged for deep submergence at all times. Before sailing, a careful check should be made to ensure all equipment designed to operate at full submergence, does so without leaking. All loose gear must be stowed and secured.

d. *Manoeuvres.* In high latitudes course and speed changes should be made gradually to prevent great directive forces unsettling the compasses.

e. *Periscopes.* Never, while submerged, should both periscopes be up at the same time.

f. *Trim.* Because of varying bathythermograph conditions, and the need for a hovering trim, it is advisable to conduct a dead slow trim at least once a watch. A good trim is mandatory in the event of an engineering breakdown affecting propulsion. A periodic depth change to obtain the sound velocity profile will provide valuable trim assistance.

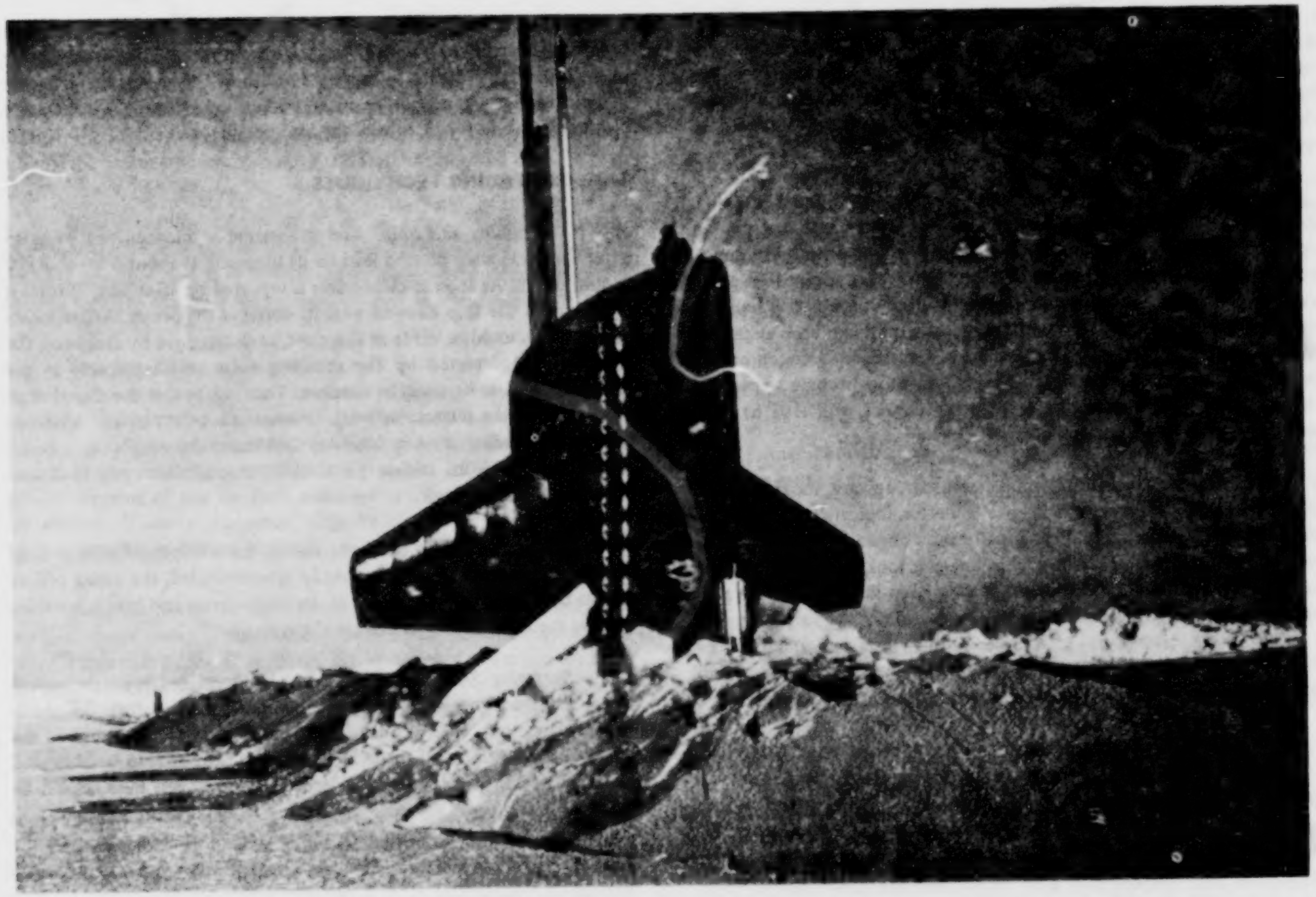
g. *Sonars.* The scanning sonar should be manned continuously, together with all upward looking sonar arrays. The scanning sonar should be echo ranging at all times when searching for and plotting a lead, and as often during the cruising period as the mission will permit. The conning officer should be able to see the upward looking echo sounder readings either on a Plan Position Indicator (PPI) scope or a recorder. The echo sounders, top and bottom, should also be in continuous operation. A specific danger sounding should be known to all watchkeepers and the recommended immediate action on reaching such a depth would be to slow down and reverse course, changing depth only if ice conditions compel it.

1403. SURFACING IN PACK ICE

a. *Finding Leads:*

(1) In the course of normal cruising, a certain amount of open water will be encountered, based on known ice movements for that area and on the season of the year. All available ice forecasting information should be studied and arrangements made to receive further forecasts en route to, and while in, the area.

(2) The navigator should maintain a record of the number and approximate size of suitable leads large enough for surfacing. This running record along a straight track will provide information on available surfacing areas and, if plotted with dead reckoning positions, provide a means whereby a submarine could return to an area suitable for surfacing with a good chance of finding it.



b. *Searching for a Lead.* If the operational situation requires it, a search plan can be adopted to locate open water for surfacing. To surface as close as possible to a specified position, an expanding square search is recommended. Other alternatives are to return to a previous plotted position, continue on a straight line search or commence a rectangular search.

c. *Identifying Lead.* The best indication of a lead will be obtained by the upward looking echo sounder with a recorder. Leads are usually indicated by the appearance of strong first and second echo traces and a moderate third trace. Young ice will be shown as a strong first echo trace and a weak second echo trace. As different upward looking sounding equipments will give different presentations, each must be carefully studied upon entry under the ice. Differences between brash, ice ridges, young and new ice and leads will soon become apparent. This, coupled with information from other devices, will lead to easy classification of the ice canopy overhead.

d. *Periscopes.* These can complement an upward looking echo sounder and in many cases will give a better indication of surface conditions. The periscope picture usually shows open water in daylight and on moonlit nights before the upward looking echo sounder indicates a lead. In addition, the periscope makes it possible to see the shadows of pressure ridges and ice blocks.

e. *Scanning Sonar.* This will sometimes show pressure ridges, the edges of leads and dense ice formations at ranges up to 2,000 yards.

f. *Plotting.* To determine the actual size of open water areas and to determine the advisability of surfacing, a plot should be generated. The axis of the lead can usually be determined by the picture on the Plan Position Indicator scope of the scanning sonar, and a course set to pass down the centre of the lead. The ship should proceed at slow speed and a Dead Reckoning plot started on a scale of 200 yards to the inch. A mark is made when all sonars indicate open water and another when any indicate ice. This establishes the length of the lead. The scanning sonar also gives an approximation of the width of the lead as the ship proceeds. After passing under the ice at the further end, the submarine turns 270° in a wide arc to cross the width of the lead estimated from the plot and the sonars. The clear water marks from the sonars are plotted again and the picture of the lead completed.

1404. SURFACING TECHNIQUES

a. *Positioning the Ship.* The submarine is manoeuvred so as to enter the previously plotted lead on its long axis at about 3 kt. and 120 ft. keel depth. As soon as clear water is reported on all sonars, "Stop" is rung up and the ship allowed to drift towards the centre. Adjustments of position should be made at this time, as determined by ranges on the ice all round depicted by the scanning sonar. With the ship in the estimated centre, headway is checked. To confirm that the ship is dead in the water, the retractable whip antenna can be raised and observed through the periscope. Any headway will cause the whip's tip to bend. Another check is to release air bubbles through an open vent and observe the bubble track.

b. *Trim.* If the ship has been slowed for a one-third trim at least once or twice every watch, as already recommended, the diving officer should be able to cope with the above manoeuvres and have a hovering trim by the time his ship is dead in the water.

c. *Surfacing.* Surfacing should never be attempted in a hurry unless a real emergency exists. Even partially blowing up before the sail is clear is dangerous. Indications of ice from sonars, excessive drift of the ice towards the ship and the evidence of headway should be corrected before surfacing is initiated. The procedures outlined here should be practiced many times by each conning and diving officer, on the way to the area, to familiarize them with the techniques and to determine the exact parameters for their submarine.

d. When it has been determined that the selected lead is clear for surfacing, the ascent is made. An ascent rate of about twelve feet per minute is desirable. A faster rate can place the ship in a precarious position as she will continue to rise from her own momentum after pumping intermittently from auxiliary tanks to sea with no headway. The ship should be brought up with a one or two degree up angle to protect the rudder, screws and stern planes. Another method is to control the ascent by blowing safety and flooding negative tank.

e. Upon reaching about 80 ft. it may be necessary to pump continuously from auxiliary tanks to sea, until surfaced, to maintain the desired rate of ascent. The fresh water layer near the surface is great enough to make the boat appear heavy when approaching the surface.

f. The retractable whip antenna may be left in the fully raised position during ascent and can be observed through the "any-height" periscope. In submarines without such a periscope, a periscope proper can be raised to determine the ice conditions overhead but it should be housed before reaching a depth where it might encounter ice. It will provide warning of any ice floes overhead or of a layer of young ice on the surface. If ice is discovered, negative should be flooded and the whip and periscope housed at once.

g. Once the top of the sail is in the clear, a periscope is raised and a fast low power sweep is made, followed by a high power sweep. If all is clear, "Prepare to Surface" is passed, the surfacing alarm is sounded and all ballast tanks are blown.

1405. PRECAUTIONS ON THE SURFACE

a. Whilst on the surface in a lead or polynya, the normal cruising watch should be maintained. While stopped, the shafts must be kept from turning to prevent propeller damage. An accurate check must be kept on the state of the lead or polynya and the submarine manoeuvred as requisite to remain in the centre. A lead can close in quickly in a strong wind.

1406. DIVING IN AN ICE AREA

a. Because of the vulnerability of topside equipment, conventional submarines should not normally surface with brash ice in the vicinity, and should submerge before ice approaches the sides of the ship.

b. A dive is made normally, except that no engine movements are ordered until the ship reaches 90 ft. In some submarines the after group vents may be opened first to keep the ship from assuming too large a "down" angle due to the forward moment of the negative tank.

SECTION II – ANTI-SUBMARINE WARFARE

1407. GENERAL

a. Anti-submarine warfare in the Arctic must take into account new weapons, new equipments and techniques. Nuclear-powered submarines, of course, can remain submerged indefinitely, can launch their missiles while submerged, or surface in pack ice if that is desired.

b. Surface ship anti-submarine tactics must be adapted to this formidable environment, as will those of long range and carrier-based anti-submarine aircraft. Ships operating in Arctic areas suffer a decreased capability, both offensively and defensively. When attempting to operate in sea ice, even if this is a practicable proposition in the first place, ships will lose speed and manoeuvrability to such a degree that they can become vulnerable to submarine attack.

c. Offensive capabilities of ships will also be limited by the effects of cold and topside icing of superstructures and armaments. The unpredictable effect of low temperatures on lubricants, batteries and fuel, together with the formation of ice and condensation, constitute some of the problems confronting those attempting to undertake ASW operations in the Arctic.

d. Weapons may not function properly and equipment generally can become sluggish, even inoperative. Hull mounted sonars are liable to damage. In addition, ice will influence weapon selection. It may be necessary, for example, to use ahead-throwing weapons, when the presence of ice would seduce or damage an acoustic torpedo, the preferred weapon.

1408. DETECTION CAPABILITIES

a. The sonar detection capabilities of surface ships and submarines vary with sea conditions. As temperature gradients in cold water areas are almost unheard of at normal submarine operating depths, a ship's sonar detection capability may be superior. However, in areas of heavy sea ice, a ship's sonar would be faced with the problem of increased reverberation thus forfeiting that advantage to the submarine, while the submarine would have the advantage of being able to operate quietly under the ice. In areas where ice is melting, there will be a considerable variation in salinity and a resulting decline in the accuracy of sonar range predictions. (See Chapter 16 – Behaviour of Electronic and Sonic Emissions.)

b. Improved listening conditions in cold water areas which are free of ice may make it possible for a surface ship to use passive detection means more effectively than with the active use of her sonar. As far as a submarine is concerned, when there is ice present, she will probably attempt to obtain visual confirmation of a sonar contact. Ships must be alert for periscopes or for disturbances in new or young ice which might betray a submarine. Lookouts should also be alert for a vapour cloud produced by a snorkel. Radar and sonar operators must also be on the alert for signs of an approaching submarine.

c. During the spring and summer months in high latitudes, when daylight hours are extended almost around the clock, surface and air visual detection chances are particularly good. Because of this a submarine may have to remain submerged, seeking concealment for very long periods of daylight to avoid detection.

1409. SHALLOW WATER LIMITATIONS ON SUBMARINES

There are certain areas where relatively shallow water inhibits submarine operations, particularly when there is the added difficulty of an overhead canopy of ice. Such areas include the Bering Sea, the area north of Bering Strait and the coastal waters of northern Siberia. Submarine attacks on shipping are not precluded in these areas, however, and surface ships should maintain constant vigilance against such a possibility.

1410. SUBMARINE VERSUS SUBMARINE

Since a submarine has the ability to remain submerged and to operate quietly, a nuclear-propelled submarine indefinitely, the most effective counter-measure would undoubtedly be another submarine possessing the same capabilities. The surest way to kill a submarine is to use another submarine. Nowhere is this more applicable than in the Arctic where ice restrains and frustrates surface ship operations.

CHAPTER 15

AMPHIBIOUS OPERATIONS IN THE ARCTIC

1501. INTRODUCTION

a. In adapting amphibious warfare techniques to the requirements of the Arctic, one of the more important planning factors to be considered is sea ice in all its forms. In any amphibious operation within sea ice areas, the attack force commander should be given ultimate authority to decide the time, the manner and the location of the attack, since these factors are inexorably influenced by ice conditions. Danger will always exist for any task force of amphibious warfare ships compelled to enter an area of pack ice. It will have to be supported by icebreakers, but even then progress would be slow and probably little evasive action could be taken.

b. Should it become necessary to effect a landing against an area protected by unnavigable ice, helicopters or air cushion vehicles would be the best means of ship-to-shore movement. Accordingly, the manner in which the operation will be conducted will be governed, both tactically and logistically, by the capabilities of the airlift available.

c. If an airlift is not available, and amphibious operations must be conducted over pack ice impenetrable to icebreakers, it is inevitable that such an operation must be limited in scope. Operations of this type would normally be mounted against undefended, or lightly held, enemy positions such as weather stations and would be followed by withdrawal from the area. Only small, lightly armed, fast moving, highly trained units could be employed.

d. If flying conditions permitted, such a force could be supported logistically by aircraft which might also be used, during the withdrawal phase, to drop trail markers to simplify cross-country navigation. The evacuation of wounded would best be done by helicopter.

1502. MARGINAL ICE AREAS

a. Marginal ice areas include those negotiable by icebreakers and ice-strengthened ships, plus areas subject to drifting ice and scattered floes. Pack ice within marginal ice areas is continuously moving under the influence of wind and current.

b. Within marginal ice areas there is always a possibility that land-fast ice may project from the shoreline, even though the sea is clear of ice for several miles. Under these conditions such ice will impose difficulties upon the landing of heavy equipment and the operation of amphibious craft over the "beachline". Divers, explosives and considerable time may be required to clear the landing area. In such circumstances, infantry organizations may have to remain unsupported by heavier weapons or equipment.

c. Landing on, and moving over, frozen pack in marginal ice areas is inadvisable for more than a few miles for fast moving units. Because of the unpredictable nature of the pack, even the movement of such units would be dangerous.

d. The logistic support of an operation could become more hazardous than the tactical venture itself. Changes of wind or current may choke open areas with pack ice so dense as to bring operations to a halt and to stop the movement of supporting ships. It is essential that adequate supplies be put ashore as rapidly as possible.

e. Logistic plans for an operation must provide alternative methods of emergency supply. If flying conditions permit, consideration should be given to the extensive use of helicopters and fixed wing aircraft for emergency drops. To facilitate ship-to-shore communications, the shore party should be given full responsibility for logistic support and be provided with the means for handling this commitment.

f. Ice can restrict the movement of naval gunfire support ships, thus effectively neutralizing this type of support. Air strike should be available as an alternative if fire support is essential. Fog and ice occurring together could prevent both means of providing fire support, and troops onshore should be briefed accordingly.

g. Ice may stop small craft from ferrying men and supplies from ship to shore. Fog can add to the difficulties. Once again the requirement for helicopters becomes apparent, and they should have an all-weather capability or units ashore may "wither on the vine"

h. Beaches can become littered with heavy floes left by an ebbing tide, making it difficult for boats to land and for men and cargo to be moved around them.

1503. MARGINAL ICE OPERATIONS

a. A beach assault within an area where sea ice predominates may be too risky to attempt. Instead, a landing should be made where ice will not jeopardize operations and enemy interference will not be a factor. The landing force would then travel overland to its objective.

b. The attack force commander must be given wide latitude in the conduct of operations, since their success will depend upon local ice conditions. He would be wise to seek the advice of icebreaker captains on the subject of ice, for they have more experience in these matters than anyone else.

c. Once the attack has been initiated, speed in landing the troops and in providing logistic support will be critically important.

d. Frequently the operations will be limited in scope, being more in the nature of a raid with a manageable number of troops.

e. The logistic support plan should include arrangements for emergency support.

f. The ship-to-shore movement plan should be based on the extensive use of helicopters, with landing craft as a second choice.

g. The employment of submarines for reconnaissance in marginal ice areas ought to be considered.

h. Reports of ice conditions can be meaningless since conditions are constantly changing under the influence of wind and tide, making it all the more necessary to give the commander on the spot authority to make last minute changes to the plan.

1504. SEA, SURF AND SWELL

a. Sea temperatures require that troops be landed dry shod. Immersion for more than a few minutes can be fatal. Men who inadvertently get wet going ashore become non-effective and must be dried out. Provision must be made, both onboard and ashore, for the handling of immersion cases.

b. Amphibious Reconnaissance Units and Underwater Demolition Teams will be restricted in their activities by the water temperature. Special individual swim clothing and equipment will be required.

c. Surf and swell are non-existent in sea ice areas because of the damping effect of the ice. In areas where ice does not inhibit the action of the sea, the same consideration will have to be given to surf and swell as in other areas of the world.

1505. EFFECTS OF TERRAIN ON AMPHIBIOUS ASSAULTS

a. The Arctic contains coastal land forms which vary from extensive coastal plains to rugged mountains, cut by deep fiords. The advance and retreat of the great ice sheets have left the marks of glaciation. Existing glaciers debouch into the sea or approach very close to it.

b. Frozen ground is a phenomenon common to the Arctic. The term frozen ground, as used here, includes permafrost, the active layer of permafrost, dry frozen ground and other variations. Frozen ground is influenced not only by constant factors including geographic conditions and temperature, but also by variable factors including such features as snow cover, vegetation, hydrology and ground heat conductivity.

c. Permafrost, particularly the fluctuations of the active layer, can influence an amphibious operation. Transport, fortifications, the effect on exploding projectiles, excavations for road and airfield construction and water supply, plus many other activities, are some of the matters to be taken into account.

d. Glaciers which reach the sea may, in some instances, provide the best approach to an inland objective. But getting a force safely on top of a glacier can be difficult and dangerous. The surface may also turn out to be too heavily crevassed for safe use. An attack force commander should seek the advice of an expert before making a decision.

e. In over-glacier operations, units must be lightly equipped for maximum mobility. Infantry should be provided with special foot-gear and sledges and tracked vehicles used exclusively. Thorough and continuous route reconnaissance must be made in advance of the main body, regardless of the proximity of the enemy. Alternative plans for supply and evacuation by helicopter should be laid.

f. In many flat coastal plains, and other poorly drained areas, lakes and ponds have been formed as the result of glacial action. In summer, when the ice has gone, they constitute an obstacle to movement inland, they become breeding grounds for swarms of mosquitoes and black flies and hinder the direction and control of forces. By contrast, in winter, frozen lakes would provide a landing force with ready-made airstrips provided the ice has had time to become thick enough to bear the weight of the aircraft it is intended to use.

g. In certain parts of the Arctic "raised beaches" commonly occur. They exist as a series of flat topped gravel ridges, left by rising land surfaces, some of which have water or ice-filled marshes behind them. These beaches, resembling giant gravel terraces parallel to the shore line, may extend for several hundreds of yards inland, increasing the requirement for beach matting. For light aircraft they make good landing strips and, if the direction suits, good roads.

h. Glacial action has left many coastal areas encumbered with great quantities of rocks and boulders, both on the beaches and in the hinterland. These can constitute a formidable obstacle to the movement of land and amphibious vehicles.

i. The general lack of significant vegetation will require :

(1) Emphasis upon camouflage discipline and exploitation of minor terrain features for cover.

(2) Increase in the amount of camouflage material to be carried.

(3) The provision by the landing force of all buildings, facilities and materials required for its operations ashore.

1506. EFFECTS OF CLIMATE AND WEATHER

a. Variations in temperature, wind, and visibility, which occur throughout the Arctic, will have effects on an amphibious assault as follows :

(1) Broad flexible operation plans, which allow latitude in time of landing and selection of landing areas, will be required.

(2) Alternative plans may be necessary, particularly where weather is subject to sudden and severe change.

(3) Alternative means of logistic support, and employment of supporting arms, should be included in the administrative and operation plans. These must be rehearsed before an operation to determine time/distance factors which may be created due to low visibility.

(4) There will be an increased dependence on manhandling and manhauling ashore in severe cold.

(5) Low temperatures will require a larger stock of rations, fuels and lubricants.

(6) Precipitation throughout the Arctic is surprisingly light but, despite this, blowing snow can produce blizzard conditions and severe drifting.

b. The severe cold of an Arctic winter will affect both the men and material of an amphibious force ashore. Low temperatures have a marked effect on glass, rubber, copper wiring, steel and explosives. They also affect the performance of motors and storage batteries. Furthermore, the effects of cold on men are severe and, when combined with wind, can produce situations that are unbearable.

c. Protection from the weather is an important factor, especially during the winter, and adequate shelters must be provided. Winter conditions may require an increase in the number of troops because of the need for frequent reliefs. More room will be needed in boats and aircraft per person, to accommodate additional clothing and equipment.

d. Low temperatures may require special facilities for the storage of explosives. Freezing temperatures may cause duds and prematures.

e. It could be unwise to use the standard five gallon can for water. Obtaining water ashore from natural sources in the winter is out of the question because they will be frozen. Water may have to be obtained from ships and be flown ashore, possibly in heated containers.

f. Air and naval gunfire support may encounter difficulties in spotting and target designation. Snow will obliterate landmarks and deep snow will cushion explosions by absorbing energy and reducing the effectiveness of high explosive fragmentation projectiles.

g. Snow on beaches and coastal terrain may frustrate aerial photographic interpretation. Map reading and orientation in a snow-covered area may be so difficult that a landing force may have to operate entirely from information obtained after landing for relay to higher echelons and supporting arms.

h. Low lying coastal fogs, low cloud cover in coastal areas, snow stirred up by high winds and periods of long winter darkness may cause postponement of landing operations. Support aviation, naval gunfire and artillery would be extremely limited in such situations. However, low visibility would provide a landing force with the advantage of concealment for grouping and movement.

1507. OTHER SPECIAL CONSIDERATIONS

a. The long summer day and long winter night of the Arctic would provide difficulties for a landing force. The lack of summer darkness may make it difficult for individuals to adjust. Tactical movements involving regrouping of forces and movement of supporting units cannot easily be accomplished under cover of darkness.

b. Arctic nights are not totally dark except when reflection conditions are poor. For example, when half a moon is visible, it is possible to see a mountain as far away as it can be seen in full daylight.

c. Naval gunfire support, ships and air support would be hampered by winter darkness and reliance would have to be placed on radar beacons for direction of supporting gunfire. Despite the hindrances which the Arctic night imposes upon operations in general, it would provide ideal conditions in which to carry out small raids of the kind which depend upon surprise and stealth for success.

d. Morale can be affected by the continuous darkness of the winter months. In summer, however, morale is likely to be considerably higher as long as adequate rest periods are observed. During winter operations, some consideration should be given to providing artificial light for operations behind the lines, particularly those involving the unloading of cargo.

e. In the vicinity of the north magnetic pole, there will be difficulties in the use of a compass. However, in most cases of areas in the Arctic beyond 200 miles from the magnetic pole, a hand compass can be used for local beach-head operations.

CHAPTER 16

BEHAVIOUR OF ELECTRONIC AND SONIC EMISSIONS

SECTION I – RADIO COMMUNICATIONS IN THE ARCTIC

1601. INTRODUCTION

a. Radio communications beyond "line of sight" limits in the Arctic pose certain problems that occur only rarely at lower latitudes. These problems are mainly caused by ionospheric disturbances which affect the behaviour of radio waves in the low frequency (LF), medium frequency (MF), high frequency (HF) and very high frequency (VHF) bands.

b. Article 1602 outlines procedures to help the communications officer maintain communications during disturbed conditions. A description of some of these abnormal conditions is given in Article 1603.

1602. COMMUNICATIONS PROCEDURES

a. During ionospheric disturbances, there are several steps a communications officer can take to overcome radio communication black-outs. It may be possible to establish communication by operating the circuit on alternative frequencies and by relaying messages via mobile or fixed stations. Accordingly, the location of all search and rescue communication facilities, and of all fixed radio stations in the operational area, should be posted in radio rooms and communication offices, together with their power output, call signs and operating frequencies. Mobile stations operating in the area must be listed in a similar manner and changes kept up to date on the list.

b. At times, because of fading of the received signal, it may be necessary for a ship to operate two separate circuits, each on a different frequency and with separate operators, whereas ordinarily, in other regions, a single circuit would suffice. This point must be taken into consideration when setting up requirements for personnel and equipment allowances. On long distance circuits, the practice of keying two or more transmitters simultaneously on widely separated frequencies has been found to facilitate communications.

c. Communication facilities for high latitude operation should include transmitting and receiving equipment with a maximum operating frequency of at least 26 MHz. Several frequency assignments, based on High Frequency prediction information, should also be available for operation in the Arctic. When normal communication is disrupted on one channel, the alternative frequencies may be tried on a pre-arranged schedule and, if communication is still poor, attempts can be made to use relay stations. Operators can best be trained in these procedures during undisturbed ionospheric conditions. This training should include rapid tuning of transmitters and receivers and the anticipation of frequency change by means of standby equipment.

d. During ionospheric disturbances, frequencies below 200 kHz may be used for communications even though radio waves between .25 – 50 MHz are absorbed in the lower ionosphere. The additional ionization formed in the ionosphere during a disturbance provides a very good reflector for these low frequencies.

e. Very High Frequency communication is sometimes impossible due to the shielding effect of mountains, fiords and enclosed harbours. When operations take place in mountainous regions, VHF circuits with aircraft should be paralleled with HF circuits.

1603. IONOSPHERIC DISTURBANCES

a. A knowledge of the behaviour of different types of ionospheric disturbances can assist the communications officer to maintain communications during these disturbances. Those which affect radio communications belong to three main types:

(1) Sudden ionospheric disturbances (SID), the "flare blackouts".

(2) Polar cap absorption (PCA), caused by "solar cosmic rays".

(3) Ionospheric storms, and mixed PCA and storm events.

b. The number and strength of these ionospheric disturbances is determined by disturbances on the sun. As is well known, solar activity goes up and down in an eleven year cycle, called the "sunspot cycle", as shown in Figure 16-I. Ionospheric disturbances follow a similar eleven year cycle: maximum activity occurred in 1957-59 and is predicted again for 1968-70.

c. Sudden Ionospheric Disturbances may occur anywhere in the sunlit hemisphere. Polar Cap Absorption events, however, are definitely high latitude phenomena and they are seen only rarely at middle and low latitudes. Ionospheric storms seriously affect radio communication circuits operating in mid and high latitudes.

d. During a Sudden Ionospheric Disturbance, radio waves are absorbed in the lower ionosphere. Between about .25 – 50 MHz attenuation may be appreciable; within this frequency range the attenuation during a given SID is very much stronger at the lower frequencies. Representative values for a one-hop communication system during a moderate SID event would be the attenuation of 900 db. at 1 MHz and 30 db. at 10 MHz. Above 50 MHz or below about .25 MHz, however, SID's are over in less than one half hour.

e. A Sudden Ionospheric Disturbance is caused by abnormal X-ray emissions from a solar optical flare. The flare radiation enters the earth's ionosphere, where it increases the ionization in the "D" region (see Figure 16-II) at heights of 35 – 50 miles. The resultant radio wave attenuation is strongest directly under the sun, and gradually weakens as the sun's zenith angle decreases. The SID is therefore relatively weak at high latitudes. The radio wave attenuation reaches its maximum value within a few minutes after the start of the SID; the return to normal depends on the duration of the solar flare and may take from several minutes up to as much as three to four hours.

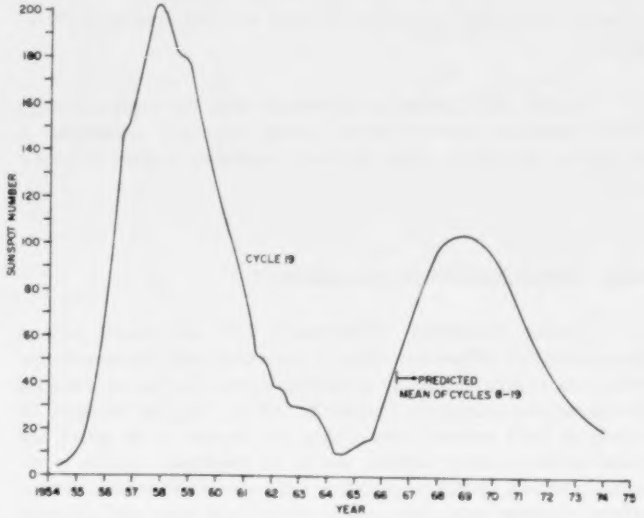


Figure 16-I. Sunspot Activity

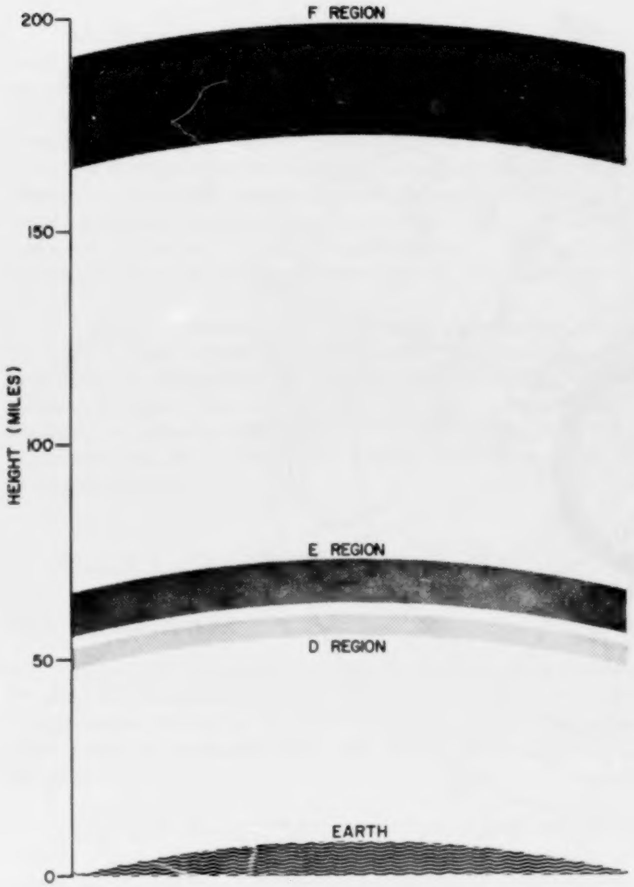


Figure 16-II. The Ionosphere

f. During a Polar Cap Absorption event, just as in a Sudden Ionospheric Disturbance, radio waves are absorbed in the lower ionosphere, and low frequencies are attenuated much more strongly than high frequencies. The PCA event differs from a SID in several important respects; it occurs only in the polar regions (about the 50th to 60th parallel of north, or south, latitude), it lasts much longer than a SID, and it affects a wider range of frequencies (about .2 – 100 MHz). During the 1949-59 sunspot cycle, about forty moderate to strong PCA events occurred, each with an average duration of two days. Nearly half of these PCA's occurred in 1957-59, near the peak of the sunspot cycle. High Frequency radio links with transmitting and receiving terminals within the Arctic Circle may become inoperative during the daylight hours of a PCA event; communication may, however, be re-established several hours after sunset, but a second blackout may occur the next day after sunrise.

g. A Polar Cap Absorption event is caused by sporadic emission of highly energetic charged particles from the sun, called "solar cosmic rays". Because of their electrical charge, the earth's magnetic field deflects the solar cosmic rays from the equator toward the polar regions, where most of them are absorbed at heights of thirty to sixty miles. The PCA events usually start within a few minutes or hours of a large solar flare, but they continue long after the initiating flare has died out, in some cases for five to six days. The radio wave attenuation depends not only on the flux of solar cosmic rays, but also on the intensity of sunlight in the lower ionosphere – the attenuation is maximum near noon and often becomes quite weak at night.

h. Ionospheric storms are more complex and somewhat less well understood than either Sudden Ionospheric Disturbances or Polar Cap Absorption events. During such a storm, radio waves may be absorbed, scattered, ducted or undergo unusual reflections. All of these effects vary with frequency, time and latitude. Some of these storms last a few hours, others last as long as a week. Some storms tend to recur at twenty-seven day intervals (corresponding to the solar rotation period) while others appear to be isolated events.

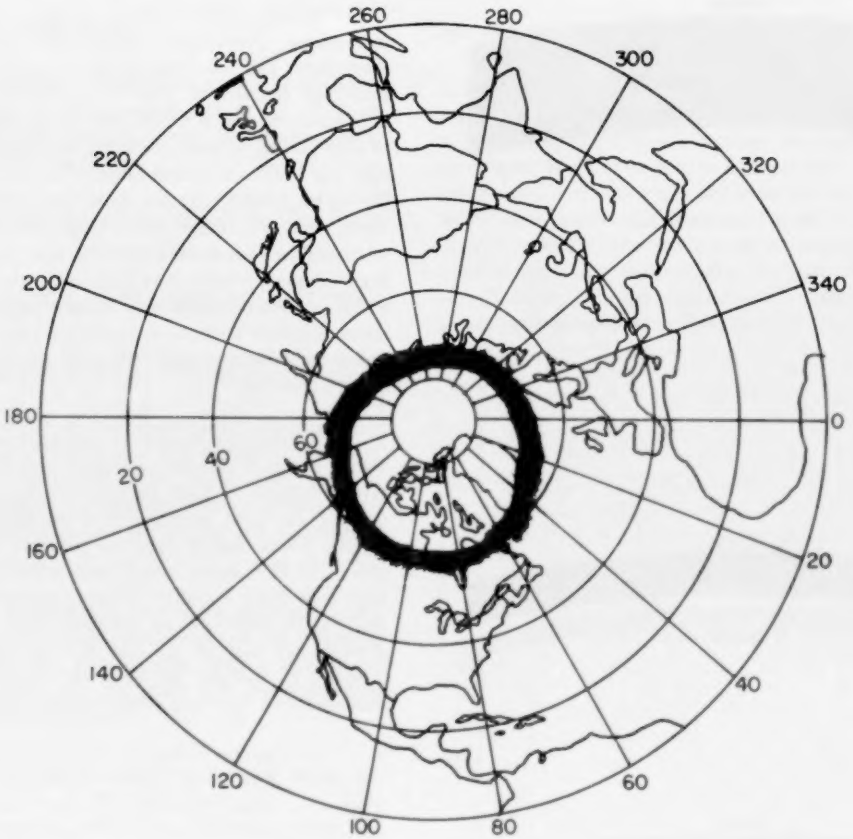

260
280
300
320
340
0
20
40
60
80
100
120
140
160
180
200
220
240
20
40
60
60

Figure 16-III. North Polar Auroral Zone

i. During an ionospheric storm not preceded by a Polar Cap Absorption event, the severest radio transmission losses occur at auroral zone latitudes (Figure 16-III), and the attenuation at the low end of the high frequency band is often sufficient to disrupt communications. When a PCA event is followed by an ionospheric storm, solar cosmic rays arrive at latitudes appreciably lower than the normal polar region, resulting in severe radio transmission losses for communication circuits operating at these latitudes. Other storm effects, such as rapid signal fading and changes in the maximum usable frequency, are much more widespread and may occur anywhere from low latitudes to the poles.

j. During an ionospheric storm the maximum usable frequency in the Arctic is usually reduced on long distance circuits, but at times may be increased on circuits less than 1,600 miles due to propagation via the sporadic "E" layer. Thus attempts should be made to use the higher frequency assignments during storms. Alternative routing, or relaying procedures, may also be required to maintain communications during an ionospheric storm.

SECTION II – UNDERWATER SOUND IN THE ARCTIC

1604. INTRODUCTION

a. Arctic seas are generally cold on the surface and, for much of the year, cold enough to support a heavy ice-cover. This Section gives an approximate measure of the effect of ice-cover on sound. travelling under water by comparing them with better known situations in temperate waters.

b. Large polar floes sometimes exceed 10 m. in draft and keels of pressure ridges often extend deeper than 30 m. Consequently the general use of hull-mounted surface-ship sonars is out of the question. Schemes for applying sonar detection techniques will thus depend on the submarine, on the ability to suspend devices from a sea ice platform or to mount them on the sea bottom.

c. On proceeding from temperate to Arctic waters, the axis of the deep sound channel, or SOFAR channel, diminishes in depth until it coincides with the surface, resulting in sound speeds which increase in depth. This increase causes horizontally projected sounds to bend upwards and to be reflected from the under-side of the ice. The downward reflected sounds will again bend upwards so that a sequence of under-ice reflections will occur. If the under side of the ice is rough, scattering will take place on each reflection producing a large transmission loss.

d. An ice canopy prevents the formation of wind waves which are the most common source of noise in ice-free seas. Instead, the ice-cover itself generates noise which depends on its mechanical properties and motion.

e. Reverberation is a time-dependent noise produced by active sonars when sound is back-scattered from false targets. A real target will be obscured in this noise if the reverberation noise is high at the same time as the target echo arrives at the receiver. Pack ice will produce large false echoes, much larger than the reverberation levels observed under moderate sea states in ice-free seas.

1605. UNDERWATER SOUND TRANSMISSION

a. Sound speed generally increases with depth in the Arctic, though with minor variations near the surface caused by seasonal changes. Typical speeds are: 1,432 m./sec. at the surface, 1,454 m./sec. at a depth of 300 m. followed by a generally uniform increase to a speed of 1,500 m./sec. at a depth of 3,000 m.

b. Sound travelling between two underwater points can be considered to follow ray paths, such rays describing the path of a perpendicular to a wave front. A single explosive shock-wave will be heard at a distance as a sequence of impulses, each impulse having travelled along a particular ray path between the source and receiving point. (Figure 16-IV.)

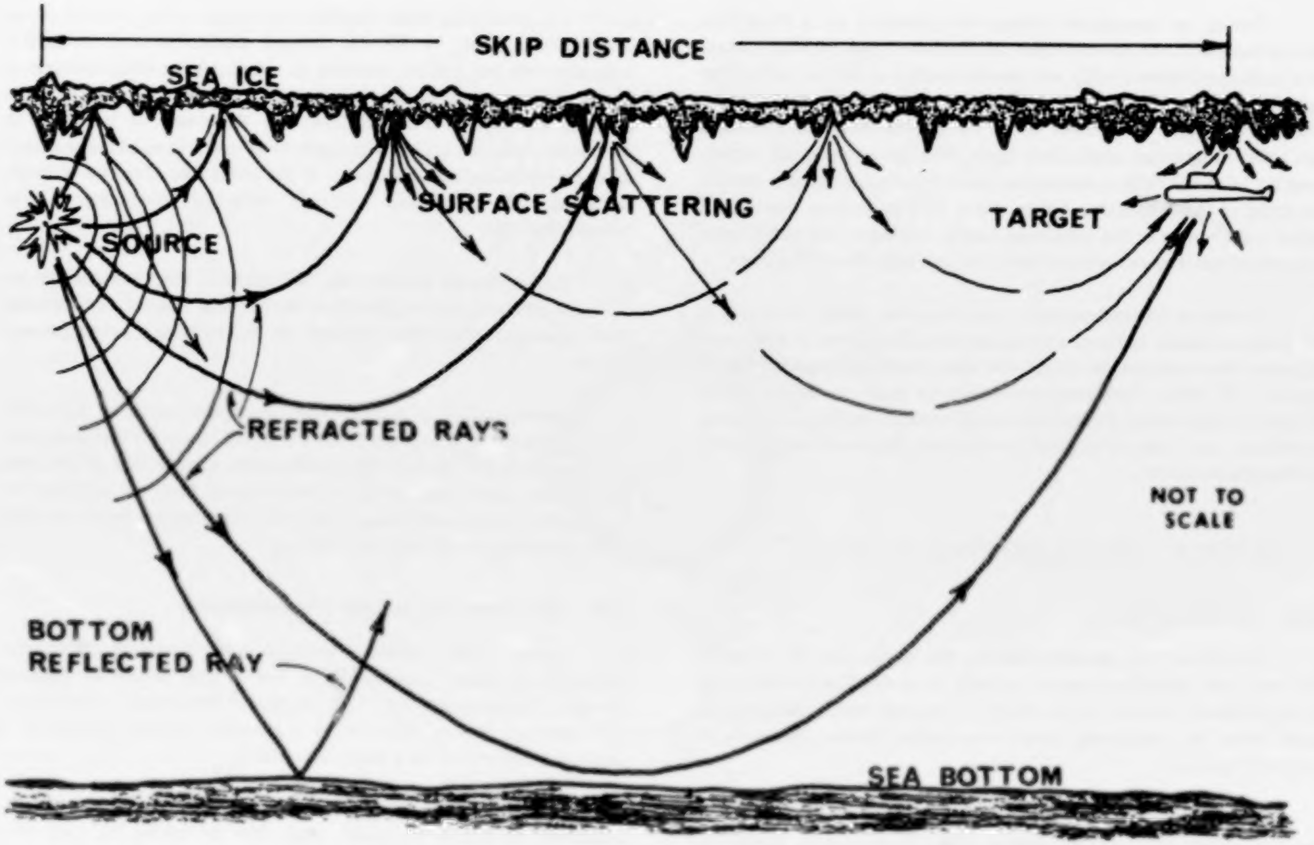

SKIP DISTANCE
SEA ICE
SURFACE SCATTERING
SOURCE
TARGET
REFRACTED RAYS
NOT TO SCALE
BOTTOM REFLECTED RAY
SEA BOTTOM

Figure 16-IV. Underwater Sound Transmission

c. In the Arctic, the first impulse to be heard will have travelled along a ray path refracted upward in the water column without striking either the bottom or the undersurface of the ice. The maximum horizontal range, or skip distance, of a refracted ray depends on the depth of the water. This skip distance is typically 12 km. for a water depth of 500 m., 30 km. for a depth of 1.1 km. and 40 km. for a depth of 2.2 km.

d. For a source depth of 200 m., the angles that such rays will be depressed below the sea surface will be 9°, 11° and 15° for water depths of 500 m., 1.1 km. and 2.2 km. respectively. All successive impulses along other ray paths will bounce from the underside of the ice at least once, each ray path having a shorter and shorter skip distance. Other important ray paths include reflections from the sea bottom as well.

e. The decrease of sound intensity along a particular ray path can be categorized as follows:

(1) *Absorption Loss in Water.* This loss, in decibels per km., is $.012f^2$ where f is the frequency in kHz.

(2) *Geometrical Spreading.* This can be assumed to be spherical, i.e., a loss of six decibels per distance doubled along the ray, except in special circumstances where some focussing or defocussing can occur.

(3) *Under-ice Bounce Loss.* For frequencies above 300 Hz, and under pack ice, bounce loss appears to be independent of frequency. This loss can vary between sixteen decibels per bounce for typically rough pack ice in the winter, to negligible loss under smooth winter ice in the spring – at least for frequencies up to 10 kHz.

(4) *Bottom "Bounce" Loss.* Bottom bounce losses in the Arctic, from the little data available, appear to range from four to nine decibels per bounce for sonic frequencies. The skip distance of a ray path, including one bottom reflection, will be less than the skip distance for the bottom-limited ray. It is evident, therefore, that ray paths which do not encounter the bottom will reach to greater horizontal distances for echo-ranging at sonic frequencies.

f. In late summer, warmed surface water in an ice-free area can intrude under adjacent sea ice to produce a shallow sound duct. Echo-ranging in this duct would be particularly effective in shallow water by eliminating the restrictions imposed by a short skip distance from the bottom limited ray path.

g. For horizontal distances greater than several skip distances with respect to the bottom-limited ray, Arctic waters generally act like surface-bounded sound channels with very rough surfaces. Sound transmission, for hundreds of km., can usefully occur for frequencies below 50 Hz where acoustic wave-lengths exceed the dimensions of under-ice roughness. Long distance passive detection, therefore, depends upon targets which can generate underwater energy in frequencies of less than 50 HZ.

1606. REVERBERATION

a. Reverberation is a time-dependent noise occurring in a sound receiver shortly after the emission of an out-going signal from an underwater projector. It is the sum of all the false signals scattered back from the volume and the boundaries of the sea.

b. Sea ice is the dominant cause of reverberation noise in Arctic regions. For winter ice, the reverberation noise for frequencies above 3 kHz is about equivalent to that expected from an ice-free sea surface with a 30 kt. wind blowing. In broken pack ice in the springtime this noise can increase by 20 db.

c. In any case, a target with dimensions of the order of the mean amplitude of the under-ice irregularities may be completely buried in the reverberation noise at all ranges.

d. In contrast with Arctic seas, waves in ice-free seas are in an ever changing state with velocities of motion which add to the sound velocities of underwater signals reflected from them. Thus sea wave motion produces Doppler frequency broadening of reverberation signals which can mask Doppler frequency shifts of targets in motion. Under sea ice, however, such frequency shifts of echoes from moving targets could possibly be observed within the higher reverberation noise.

e. Reverberation noise can also be minimized by using highly directional sources and receivers to exploit optimum ray paths. Such paths could provide time discrimination between echoes and reverberations for targets spatially separated from the ice surface.

1607. AMBIENT NOISE

a. Ambient noise is a composite noise from all sources in an under-ice environment irrespective of sonic devices used to observe it. Amplifier noise, platform noise, and flow-noise caused by the motion of a sonic device, are considered system noises and are excluded in this description.

b. Ambient noise under sea ice can be separated into the following categories:

(1) Above 50 kHz, a major noise source is thermal noise, which is caused by the agitation of water molecules.

(2) Noise originated at the ice-covered sea surface.

(3) Biological noise from soniferous fauna.

(4) Man-made noise from underwater explosions, ice breakers and other sources.

(5) Low-frequency naturally occurring noises, mostly sub-sonic, caused by earthquakes, microseisms, standing and propagating waves on ice-covered seas.

c. In category (3) above, apart from occasional seal noises and loquacious pods of beluga or white whale, biological noise sources are rare under sea ice. Categories (4) and (5) above are important noise sources at low and sub-sonic frequencies, because of the low-pass filtering effect of the rough ice canopy. An explosive charge set off hundreds of km. away can produce sub-sonic noise (below 30Hz) which is observable for hours in the Arctic Ocean basin. Similarly, other sources of low frequency energy can raise the general background noise, because of their ability to travel long distances with relatively little attenuation.

d. In contrast to the foregoing, ice-noise in category (2) above, observed in frequencies greater than 100 Hz or so, will be more local in origin and will be generated within the circular surface area roughly defined by the skip-distance of the bottom limited ray. This noise generating area will shrink as the water shoals. The ice-noise category of (2) is by far the most important between the frequencies of 100 Hz and 30 kHz.

e. Ice noise, therefore, replaces sea-wave noise as it is experienced in ice-free seas. A useful comparison can be drawn between the noise power generated underwater by particular "sea-states" and the noise generated under sea ice. Under sea ice, noise levels range all the way from "sea-state 3" to almost 20 db. below that of a "sea-state 0" equivalent noise level. Under-ice noise is usually impulsive and often quite sporadic in contrast to sea-wave noise, which is relatively continuous in its generation.

f. Very cold sea ice is brittle. Surface cracking in the winter, from shrinking caused by declining air temperatures, produces energetic underwater sound pulses or "thermal" noise. Such cracks are thinly distributed over a wide area. For rapidly cooling air, the average thermal noise level can exceed an equivalent "sea-state 3" level. Since this noise is highly impulsive, the peak impulse energy becomes important, particularly when observed near the ice.

g. In contrast, rising air temperatures in winter cause the ice surface to expand. Noise can then diminish to less than a "sea-state 0" level. An increase in snow cover will reduce the effects of air temperature changes and will permit the sea ice temperature to rise.

h. Warmer sea ice is also less brittle. These last two conditions are normal in the late spring so that beneath land-fast ice, the noise can diminish until it is well below an equivalent "sea-state 0" level.

i. Wind moving over icefields generates underwater noise from miniature eddies which oscillate in the lee of snow and ice crystals. This noise increases with wind speed and can reach a "sea-state 1" level at 10 kHz for a wind speed of 22 kt.

j. Important under-ice noise is also generated by the disintegration and re-establishment of the ice cover. In winter and spring, snaps, squeals and groans occur sporadically, often accompanied by tearing noises. The average noise level produced is usually low, between "sea-state 0" and "1", but the peak levels can be high enough to inactivate nearby sonar systems temporarily. This background noise is produced by the rafting and crumbling of thin new ice.

k. Ice cover during an Arctic summer is seldom complete and appears to do little more than inhibit the formation of surface waves by the wind. Surface water in summer is nearly fresh so that ice rind forms as air temperatures drop below 0°C. Rafting and crumbling of this rind can increase the noise from less than a "sea-state 0" to more than "sea-state 1" levels. On the other hand, the slow jostling of summer floes produces remarkably little noise. Noise under ice in the Arctic summer is generally more continuous and less impulsive than in winter and spring.

1608. RANGE PREDICTION

In areas where ice is melting, there will be a considerable variation is salinity. This will degrade the accuracy of sonar range predictions.

CHAPTER 17

SURVIVAL

1701. INTRODUCTION

a. Impressive advances continue to be made in the development of clothing and equipment for survival. However, when faced with the necessity of taking steps to ensure survival, an individual's unfavourable reactions may render him incapable of using the available resources.

b. One of the most important requirements for survival is a capacity to accept immediately the reality of an emergency and an ability to react appropriately to it.

c. Acquaintance with survival technique is an important factor affecting one's ability to stay alive. Relevant knowledge and training may be put directly to use in meeting the emergency, and will also contribute to a feeling of confidence whereby fear is reduced and panic prevented.

d. If a man is caught unprepared in a survival situation, he becomes handicapped and his chances of coming out with a whole skin may be more a matter of pure luck than anything else. Anyone who has taken the trouble to learn about the subject, who has planned what to do under a variety of circumstances and who has equipped himself with certain essential survival aids, has a fighting chance. Equally important is an inner determination to survive – come what may.

1702. FEAR

a. Fear is a very normal reaction which confronts any man faced with an emergency. Fear influences a man's behaviour and thus his chances of survival – it can ruin his chances or may even actually improve them. There is no advantage in avoiding fear by denying the existence of danger. There is always something which can be done to improve a survival situation.

b. How a person reacts to fear depends more on himself than on the situation. It is not always the physically strong or happy-go-lucky person who most effectively handles fear; a normally timid or anxious person can often respond more coolly and effectively to an emergency.

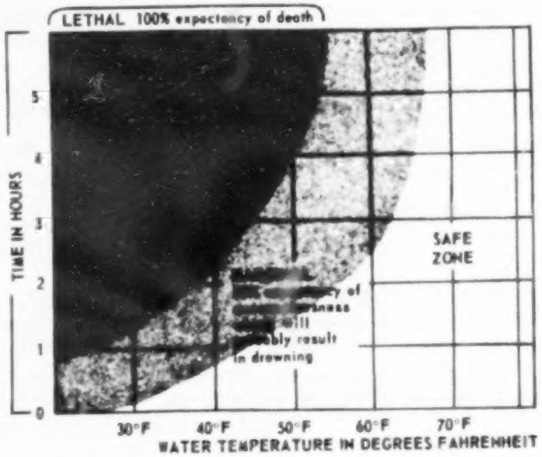


Figure 17-I. Survival Chart

WIND SPEED		TEMPERATURE (DEGREES FAHRENHEIT)													
MPH	KNOTS														
		32	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-40
5	4	32	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-40
10	9	22	14	8	2	-4	-10	-15	-21	-27	-33	-39	-45	-50	-70
15	13	16	7	1	-7	-13	-19	-23	-32	-38	-44	-51	-57	-64	-85
20	17	11	2	-5	-12	-19	-23	-32	-39	-46	-52	-59	-66	-76	-96
25	22	7	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-85	-100
30	26	5	-5	-12	-19	-27	-34	-41	-48	-56	-63	-70			
35	30	3	-7	-14	-22	-29	-37	-44	-51	-59	-66				
40	35	2	-8	-16	-24	-31	-38	-46	-53	-61	-68				
		LITTLE DANGER			INCREASING DANGER					GREAT DANGER					
		DANGER OF FREEZING EXPOSED FLESH FOR PROPERLY CLOTHED PERSONS													

INSTRUCTIONS

a. Enter table by selecting the existing surface temperature (along top), to the nearest 5° interval.

b. Move straight down the selected column to the level adjacent the existing wind speed reading.

c. Table reading at this point gives the "wind chill temperature" * for the selected temperature and wind speed.

* "Wind chill temperature" is that temperature which, associated with a five knot wind, would have the same cooling effect as the existing conditions of wind and cold.

NOTES

a. This table is used to relate the cooling effect of a given temperature and wind speed to an equivalent lower temperature and a standard 5 MPH wind speed.

b. Wind may be calm but freezing danger great if the person is exposed in a moving vehicle, under helicopter rotors, in propeller blast, etc. It is the relative rate of air movement that counts - the cooling effect is the same whether you are moving through the air or it is blowing past you.

c. The effect of wind will be less if one has even slight protection for exposed parts - light gloves on hands, parka hood shielding face, etc.

Figure 17-II. Wind Chill Temperature Chart

1703. COLD

a. Cold is a much greater threat to survival than is generally realized. It not only lowers a man's ability to think, but also tends to weaken his will to do anything. Cold is insidious, and while it numbs the body it also numbs the will. Because it is hard to keep moving, and harder to fight off an overwhelming desire to sleep, a man can forget his goal ... to survive.

b. Sea water temperatures in the Arctic vary from −1°C to 1.6°C. A man struggling in water at these temperatures might last about three minutes. Some may last longer than that before expiring. Others will fare much worse, for instance older men, those suffering from a heart condition or men of slight build. All would be dead in any event within five minutes. Therefore, the numbing shock of bitter cold water and accompanying wind chill is the paramount factor influencing most Arctic marine survival situations (see Figures 17-I and 17-II).

c. For details concerning the symptoms and treatment of hypothermia, immersion foot, frostbite and snow blindness, refer to Chapter 9.

1704. MAN OVERBOARD

a. In most ships there is to be found one man who will arrange matters so that he works in a dangerous location without benefit of lifejacket, lifeline or line tender. If he falls overboard under such circumstances, he has only himself to blame. While every effort will be made to rescue him, all hands should understand that in Arctic waters such an attempt can be little more than a gesture. A man who falls overboard from a ship at anchor or alongside may stand a slightly better chance, but only if someone has seen him go.

b. All personnel must be made well aware of the bone-chilling water temperature and the consequences to them of falling over the side.

c. Whether at anchor or alongside, all ships must have an effective organization to cater for men who, for one reason or another, fall overboard. This lookout organization should also maintain a constant watch on laden boats ferrying people and cargo ashore or between ships.

d. In a man-overboard situation, a lifebuoy is better than nothing for it will also mark the spot where the victim may be located. A better alternative for cold waters would be an inflatable life-raft, specially placed in the ship for just such an eventuality, self-inflating and fitted with a drogue to prevent it from being blown out of reach. But to be of help, such a life-saving aid must hit the water within easy reach of the man.

e. After casting a lifebuoy or raft over the side, the ship must make an effort to recover the man by manoeuvring into a suitable position just as quickly as her type and size will permit. A good ship-handler, who has not only thought out the problem beforehand but has also rehearsed it, may make all the difference between a corpse and a case of severe hypothermia. It would be futile to use a boat. A swimmer, prepared to expose himself to the cold water, must be ready to go over the side the instant his ship is laid alongside the victim; he should be tethered and have another line with which to grapple for the body.

f. Any man plucked from cold water will require immediate and expert medical care; as will his rescuer.

g. In circumstances when it would be impossible to stop, or in heavy unhandy ships, an escort may have to be diverted, provided there is no doubt about the man's position and that such an alternative will take no more time. A suitably equipped rescue helicopter, nearby and ready for action, as would be the case in a Carrier force operating aircraft, would be an ideal solution.

h. No effort should be spared to ensure that, as far as humanly possible, a man-overboard problem in the Arctic does not occur. By indoctrination and precautionary measures, ships should make it as difficult as possible for such a situation to arise.

1705. ABANDON SHIP

a. Stranding, fire or explosion can befall any ship – even in Arctic waters. Whatever the cause, in the Arctic, a large number of men could be forced to abandon ship in circumstances of darkness, fog, ice and heavy seas, or they may be compelled to take to the ice.

b. In warmer climates, in such circumstances, men who were not fortunate enough to find space in a boat, could go over the side wearing lifejackets in the knowledge that they had as good a chance of surviving as those in boats. But in water of Arctic temperatures, swimmers would have a life expectancy of only a few minutes.

c. Modern inflatable liferafts have come a long way in design, reliability and capacity. They inflate automatically, complete with weather canopies, in about thirty seconds to provide better shelter than boats ever did. In a growing number of ships the lifesaving role is being switched from boats to inflatable rafts because the latter have proved themselves to be so remarkably efficient. Such rafts, then, appear to be the best solution to the chilling prospect confronting a ship's company compelled to take to the water. If ships on Arctic service are supplied with rafts sufficient to accommodate one and a half times the ship's crew, the chances of group survival in these circumstances will be much improved. In addition, every man should have a "quick-donning" immersion suit to provide additional protection from the elements (see para 1706 d).

d. But if inflatable rafts are to be effective lifesaving devices, men must be trained in their use, and have confidence in all their features. Only then will they be able to make the best use of these efficient lifesaving devices. One raft should be supplied to every ship for instructional purposes on a permanent basis.

e. Rafts should be equipped with high intensity lights and larger rafts should have some electronic means of homing rescue forces. Radar reflectors, depending upon winds and local ice conditions, may prove helpful in aiding detection by rescue forces.

1706. IMMERSION SUITS

a. In the Arctic, aircrew should invariably wear immersion suits or wet suits for over-water flights in fixed-wing aircraft. These suits may be a trial to put on and be uncomfortable to wear for long periods, but the alternative might be even more uncomfortable.

b. Aircrew of small helicopters may be given some discretion in this matter if they are operating over an area where there is a significant amount of sea ice. In such circumstances the sea is usually calm and helicopters can put down on the ice, or if equipped with floats (as they should be for Arctic operations) sit on the water with little fear of being upset.

c. Large helicopters, however, must be equipped with some form of emergency flotation, and aircrew should always wear immersion suits for over-water operations. An exception could be made to this rule if flying is to take place over fast ice, or where there are heavy floes covering at least five-tenths of the sea and which are thick enough to support the weight of the machine.

d. A "quick-donning" immersion suit has been developed by the United States Navy for use by helicopter passengers and others who may become involved in a short term Arctic survival situation. Made of a light-weight rubberized vinyl material, International Orange in colour, these waterproof suits are intentionally large and loose fitting garments intended to be worn over a person's clothing but inside a life jacket. Because of their generous dimensions, they are easy and quick to don and fit all shapes and sizes with equal facility. Neck and wrists are elasticized to keep water out. By providing protection for those who would otherwise surely succumb to the effect of an involuntary immersion in very cold water, these suits could be the means of saving many lives.

1707. HELICOPTER SURVIVAL EQUIPMENT

a. The amount of survival equipment which can be carried in a helicopter must obviously be kept to a minimum, but the following items are considered essential for Arctic operations:

(1) Shelter tent (two man capacity).

(2) Emergency rations (10 days per man).

(3) Emergency radio.

(4) Rifle and ammunition (30-06 or equivalent and 50 rounds).

(5) Axe.

(6) Signalling mirror plus flares and smoke bombs.

(7) Two-burner Coleman stove and fuel.

b. It is an accepted rule among those who travel in the Arctic to always have their sleeping bags with them in case of an emergency or even an unexpected change in plan. But sleeping bags (and tents, stoves, etc.) are bulky items and for naval operations a special decision would be required specifying precisely what survival equipment should be carried for the ship-borne helicopter operations envisaged.

1708. EMERGENCY AIRCRAFT LANDINGS IN THE ARCTIC

a. *Immediate Action - Forced Landing on Land*

(1) Remain away from the aircraft until engines have cooled and spilled fuel has evaporated.

(2) Check for injuries, give first aid and make the injured comfortable.

(3) Check clothing, paying particular attention to gloves and footwear. Keep snow brushed from clothing and avoid getting wet.

(4) Throw up a temporary shelter. If necessary start a fire, make hot drinks.

(5) Salvage all personal and aircraft emergency gear from the aircraft.

(6) Drain the oil and let it fall on the snow where it can congeal; it can be used for fuel later. Congealed oil can also be used for smoke signal fires.

(7) Get the emergency radio or the aircraft radio operating on a schedule. If no contact, supplement voice communications with emergency radio signals on a scheduled basis.

(8) Do not try to live in the aircraft – it will be too cold. At first glance, the aircraft seems a logical shelter but it is a poor one. There is no possibility of bringing the inside temperature above the ambient temperature. The fuselage, exposed to piercing winds, will act as a heat sink that will drain away body reserves and emergency supplies.

(9) Even though every effort will be made to effect a rescue, plan for a long stay. Poor weather may delay matters.

(10) Individuals in the survival group should be given specific duties.

(11) Prepare signals so that the group can be spotted from the air.

(12) Start a log book. Include date and cause of crash; probable location and other pertinent data.

(13) Determine the position by the best means available and include this in radio messages.

(14) Conserve electrical power.

(15) On hearing an aircraft, sweep the horizon with a signal mirror at frequent intervals.

b. *Decision to Stay or Leave Aircraft*

(1) The best advice is to stay with the aircraft and await rescue. Most rescues are made when people remain with their aircraft because, with current search and rescue procedures, the general vicinity of your position will be known. A downed aircraft also makes a good radar target.

(2) There may, of course, be exceptions to this advice if the aircraft is down on sea ice which is threatening to fail under its weight.

(3) A downed aircraft should be left only when:

(a) The position is certain and it is also certain that with available equipment and resources, shelter, food and help can be reached.

(b) After waiting several days, it is obvious that rescue is not immediate.

(4) Advantages of staying with the aircraft:

(a) It is easier to spot from the air than men travelling.

(b) The aircraft will provide signalling and other material (cowling for reflector signals, gasoline and oil for fires, generator for radio power).

c. *Knowledge of Location.* The crash position must be known in order to decide intelligently whether to wait for rescue or to determine a destination and route if travel is decided upon. Maps, charts and flight data should be studied and celestial observations taken.

d. *Immediate Action – Forced Landing on the Ice*

(1) Evacuate the aircraft immediately and take care of the injured. If the ice is thin, the aircraft will depress the ice and may eventually break through.

(2) Check clothing to ensure it provides maximum possible protection against cold and wet weather.

(3) Establish a temporary shelter at least 50 yards from the aircraft. If possible build a fire inside.

(4) Attempt to establish radio contact with anyone, station, ship or aircraft, and in so doing establish a systematic procedure.

(5) Survey the area to determine the safest camp site. Seek a thick ice floe in the general vicinity of the plane. Do not

camp on a young (smooth) ice floe which may be thin and will be the first to break up. Consider the availability of food and water and the distance to the crashed aircraft.

(6) Build a camp. Do not use the aircraft as a shelter unless absolutely necessary, for it may become imperative to move in a hurry as the ice can break up quite suddenly. Also, if the aircraft is being lived in, essential supplies may be lost if it sinks.

(7) Find and mark a safe landing area for rescue planes and/or helicopters.

(8) Do not get separated. There is always a danger of the ice floes breaking apart.

(9) Unless it is known that land is within walking distance, it is best to remain as close to the scene of the crash as ice conditions will permit.

e. *Immediate Action – Forced Landing in the Sea*

(1) Activate and board life rafts. Stay clear of aircraft and out of fuel-covered waters, but remain in the vicinity until it sinks.

(2) Search for missing personnel.

(3) Salvage floating equipment. Stow and secure all items and check raft for inflation leaks and points for possible chafing.

(4) In cold weather don exposure suits. Rig a wind-break, spray shield and canopy. Huddle together; exercise regularly.

(5) Check physical condition of all aboard. Give first aid if necessary. Take seasickness pills if available. Wash off fuel which occupants may have collected on themselves and their clothing.

(6) If there is more than one raft they should be joined together with at least 25 feet of line. Connect rafts only at the life line around the outer side. Unless the sea is rough, shorten the line if an aircraft is seen or heard. Two or more rafts close together are easier to spot than scattered rafts.

(7) Get emergency radio into operation. Directions are on the equipment. Use emergency transceiver when aircraft are known to be in the area. Prepare other signals for instant use.

(8) Keep compasses, watches and lighters dry in waterproof containers.

(9) Keep a log. Record the best navigation data available. Also record the direction of the wind, swells, times of sunrise and sunset and any other facts that may be of use later.

(10) Save water and food by saving energy, and ration if necessary.

(11) Keep signal mirrors handy; use the signal panel and dye marker whenever an aircraft is in the vicinity.

f. *Protection Against Exposure*

(1) In cold oceans every effort must be made to stay dry and keep warm when adrift in life-rafts. Shelter behind spray and wind shields. Remove, wring out and replace outer garments or get into dry clothing.

(2) Personnel with dry clothes should share them with those who are wet, and the latter should have the most sheltered position in the raft.

(3) Don any extra clothes available. If no exposure suits are provided, men should drape extra clothing around their shoulders and over their heads. Keep clothes loose and comfortable. Try to keep the floor of the raft dry, and for insulation cover it with canvas or cloth.

(4) Take mild exercise to restore circulation. Repeatedly bend and open fingers and toes. Exercise shoulder and buttock muscles.

(5) Warm hands under armpits. Periodically raise the feet and hold them in that position for a minute or two. Move face muscles frequently to detect frostbite. Shivering is normal, it is the body's method of quickly generating heat.

(6) Give extra rations to men suffering from cold exposure.

g. *Raft Seamanship*

(1) Put out the sea anchor immediately. A sea anchor properly used will hold a raft into the wind, check drift and provide the best and often the only means of steadying the raft in a seaway to prevent broaching and capsizing. Do not attempt to navigate a raft unless land is in sight or land is within a reasonable distance. Take every precaution to prevent the raft from turning over. In rough weather men should sit low with their weight distributed to hold the weather side down.

(2) Men should not sit on the sides or stand up. There should be no sudden movements without prior warning. Every precaution must be taken to keep the raft stable and dry.

1709. OCEAN SURVIVAL

a. *Living Without Food and Water*

(1) Do not eat if there is a lack of water. The body uses up water in digesting food, and the elimination of waste products also draws water from the tissues.

(2) A man will last longer if he conserves his energy by relaxing mind and body and guarding against exposure to cold.

b. *Water*

(1) Rain, ice and the body fluids of animal life are common sources of water.

(2) Seawater should not be drunk as it only increases thirst and, by drawing body fluids from the kidneys and intestines, causes convulsions and delirium.

(3) Do not drink urine, as any urine passed will be almost as concentrated as seawater, and will have the same result as in (2) above.

(4) When water is plentiful a man should drink all he can hold. Little of the water taken when a person is dehydrated is lost through perspiration or urination.

c. *Food*

(1) The sea is far richer in different forms of life than either the land or fresh water and, if drinking water is available, there should be little danger of starving.

(2) Fish found in the Arctic are edible, either raw or cooked. None is known to be poisonous. The heart, liver and blood of fish are edible, but the intestines should be avoided unless cooked. Stomachs of large fish may contain partially digested fish, which are also edible. Fish eyes contain a large percentage of water. Some fish eggs are, however, poisonous and those found growing in clusters or clumps on rocks or reefs should not be eaten.

(3) Never fasten a fishing line to anything solid, it may snap when a large fish strikes. Fish are more apt to see and strike at moving bait. Any part of the flesh of a bird or fish makes good bait and it need not be fresh.

(4) When fishing, vary the time of day and the depth of the bait to catch different species. As many fish come to the surface at night, and may be attracted by lights, fish for them accordingly by using a short line.

(5) Seaweed is tough and salty, absorbs water from the intestines and is difficult to digest. Eat it only if plenty of water is available.

(6) Small edible crabs, shrimps and fish inhabit coastal seaweed and patches of sargasso at sea. Use a drag behind a raft or boat to collect the seaweed, then shake it to catch the food.

(7) All sea birds are edible and nourishing, though not always flavoursome. Gulls, albatrosses, terns and gannets may be caught by dragging a baited fish-hook behind a raft. A flat sharp-edged triangular piece of metal dragged behind a float will bring gulls or albatross within shooting range. Gannets, once settled on a raft, often display little fear of man and are easily caught.

(8) Whatever bird is caught, use all of it. Small feathers can be used to make a fly or lure. A spinner can be fashioned from the beak. Bones can be used as hooks. The skin is nutritious, but if warm clothing is a pressing problem, skin the bird down the back and use the breast as a cap, ear muffs, shoe linings, etc.

(9) Marine molluscs such as oysters, clams, scallops, whelks, periwinkles, barnacles and conches are in practically inexhaustible supply throughout the world. They can be eaten cooked or raw.

1710. ANOXIA

a. Anoxia or an insufficiency of oxygen, can occur when men attempt to live in a poorly ventilated shelter. When men breathe, the percentage of oxygen in the air drops while the percentage of carbon dioxide climbs. The smaller and more airtight the space, and the more people there are in that space, the sooner will these conditions manifest themselves.

b. Close observation of a burning candle is essential in any Arctic shelter. When the percentage of oxygen in the air drops from 20% to 16–17% a candle will go out. This occurs, however, before the occupants themselves will be seriously affected by anoxia and in time for them to bestir themselves and get into fresh air. Carbon monoxide poisoning is, however, an entirely different matter.

1711. CARBON MONOXIDE POISONING

a. Everyone must be constantly alert for the possibility of carbon monoxide poisoning resulting from incomplete combustion of fuel. Use of petroleum products in internal combustion engines and stoves in the Arctic is a common source of carbon monoxide poisoning.

b. Those who take refuge in tents, snow houses, or other Arctic shelters must be aware of this danger, because ventilation may be inadequate or ventilators may become blocked. This warning also applies to boats and vehicles where ventilators may become obstructed or exhaust pipes plugged by snow.

c. Carbon monoxide is odourless, tasteless and colourless. Symptoms of poisoning are a loss of peripheral vision, dimmed vision, headaches, dizziness, nausea, exhilaration or lassitude and chest pain. Some, or all, of these may give sufficient warning to enable a man to save himself by breaking out into the fresh air before he is overcome, collapses into unconsciousness and dies.

d. It is essential to provide active ventilation in tents and other shelters even if this means some loss of precious heat to incoming cold air. Leaded gasoline burned in stoves produces lead oxides which are irritating but non-toxic in small amounts. Smarting eyes, running nose or coughing produced by these are a warning of carbon monoxide buildup.

e. Treatment is to move the subject into the fresh air, and if necessary, apply artificial respiration. Give 100% oxygen (with 6–7% carbon dioxide to stimulate hyperventilation). Keep warm and quiet in bed for at least eight hours. Too early exertion may produce heart failure.

1712. FIREARMS

a. Taking a rifle or pistol into a warm shelter from the outside cold will cause heavy condensation, leading in a short space of time to serious rusting and corrosion of the working parts. Weapons should either be left out in the cold or, if this is not advisable for other reasons, be taken down and cleaned every time they are moved from a cold to a warm environment.

b. Over-gun rather than under-gun. Do not hunt hares with a .22 in bear country; shotguns and large calibre rifles also kill hares even if they do leave them a little tattered. If bird hunting with a shotgun, always carry two or three rifled slug shells for self-protection against bears.

1713. DANGEROUS ARCTIC ANIMALS

a. The most dangerous animal to an Arctic survivor is the polar bear. This large and powerful carnivore inhabits the coastal regions of the Arctic, is truly nomadic and wanders the ice pack year-round in search of food.

b. Bears, being afraid of nothing, are understandably inquisitive and curious of man. Behaviour should not be mistaken for aggressiveness or hostile intent. Not at the outset, anyway. Should a bear's investigations become uncomfortably attentive, he may be discouraged and frightened off by loud noises and activity. If this also fails, retreat is the next alternative.

c. Unless a person's life is actually threatened, it is wiser not to try conclusions with a bear as they are exceedingly difficult animals to kill. The head shot is not recommended because the shape of the skull may simply deflect a bullet. Furthermore, a bear bobs his head and moves it from side to side, offering a continually moving target. The shoulder shot is preferred.

d. A bear with cubs is extremely dangerous if molested. To approach a polar bear cub, whether or not its mother is nearby, is to invite certain retaliation.

e. Polar bear meat makes good eating but trichinosis is as widespread in bear meat as in most other Arctic animals. All meat must, therefore, be cooked for a long time to destroy these parasitic worms. Boiling bear meat thoroughly in small pieces, followed by frying to make it more palatable, might be the best solution. Trichinosis can be a fatal disease so, for survival under circumstances where boiling is impossible, the risk of infection will have to be accepted. The liver of the bear is poisonous and must not be eaten.

f. Musk ox are found in some parts of the Arctic and are not dangerous unless approached very close.

g. Arctic wolves (white in winter, dirty gray in summer) are normally frightened of man but can become aggressive.

1714. INSECTS

a. Mosquitoes, midges and flies are as common ashore during the Arctic summer as they are in lower latitudes and can cause a survivor great distress. There is, however, no danger of disease from their bites. Lacking head nets and chemical repellants, about the best tactic is to avoid marshy low-lying ground, move along high ground preferably into the wind and cover as much exposed skin as practicable.

b. Survival kits should always include head nets, netting material and some form of insect repellant.

1715. WINTERING-IN

a. In the past, ships wintered in the Arctic as a matter of course because they could not complete their work in one season, or because the onset of winter caught them before they could reach open water and a route home. But these ships went prepared for such an eventuality and were stored and provisioned for prolonged Arctic service.

b. Today, the possibility of a ship involuntarily having to winter in the ice is remote. With powerful icebreakers, efficient communications and ice and weather forecasting services available, a ship would have to be remarkably unlucky or most ineptly handled to become trapped. A ship could, however, become temporarily beset but she would almost always be broken free before final freeze-up.

c. An icebreaker, or an ice-strengthened ship, might conceivably become beset late in the season and be unable to extricate herself or be extricated by icebreakers. In that event it is to be hoped there would be an opportunity for the unfortunate vessel to manoeuvre herself into a more suitable location, preferably a refuge which afforded some protection from the assaults of ice under pressure. If this should prove impossible, so that she had to remain in the open sea, she could be exposed to destructively powerful forces from pack ice as it worked during the winter. A thin-skinned ship, in such circumstances, could be gripped and crushed, becoming a total loss later when the ice finally loosened its hold and let her founder.

d. All ships which have been frozen-in have had to endure ice pressure. When this has ended in disaster it has usually followed a nearby break-up of ice which has left large areas of newly frozen leads and polynyas. These, offering no resistance to heavy ice moving in upon them, leave the ship to bear the full brunt of such ice herself.

e. The key to ship protection in the pack is to ensure that pressure, where unavoidable, will be applied uniformly throughout the ship's length. She should be worked in between uniformly thick floes of nearly equal size, with no polynyas or open leads nearby. These floes will cushion the pressure which is bound to be experienced during the constant movement of the pack and, if a break-up occurs, provide a measure of protection.

f. If there is any choice in the matter, a ship compelled to winter-in should select a harbour where protection from driving ice is afforded to seaward of her by rocks, shoals or islands. The best type of protected harbour is a narrow, deep, fiord-like channel where mooring lines can be run ashore. An alternative site should be selected to which the ship could be warped in the event the first site, for one reason or another, proves to be unsuitable or unsafe. The practicability of rigging cables athwart the seaward side of the refuge, to impede ice which might otherwise drift down upon the ship, should be investigated. Moor in shallow water, making allowance for the height of the seas and the tidal range to be experienced. Lay out wires and anchor cables to suitable moorings ashore.

g. A good fresh water supply is an important consideration if there is any doubt about the ability of the ship's evaporators to function throughout the winter. Glacial ice gives roughly twice the water per fuel unit in half the time that snow does when melted, and it is also cleaner. To be on the safe side, all drinking water should be purified either by boiling or by chlorination.

h. The direction of the wind must also be considered. The ship and any objects which may be stored on the ice nearby, should be aligned with the least dimension facing the prevailing wind to reduce the formation of snow drifts.

i. Preparing a ship for a winter in the ice would be a challenge to all departments. After securing her, and making everything as shipshape as possible, the greater part of the crew should be removed, leaving behind a rear-guard which could, weather permitting and the distance from the nearest land not being too great, be relieved at intervals during the winter. How these transfers might be undertaken would depend on circumstances. Darkness, wind and unsuitable landing conditions might rule out fixed wing aircraft. Distance might rule out helicopters, and the absence of nearby polynyas an evacuation by submarine. In such circumstances the crew might have to remain onboard because a major journey over the ice by sailors unused to such travel perhaps should not be attempted.

j. The following steps should be taken in laying up the ship:

(1) *Diesel Machinery.* The sea water intake to the engines should be securely closed. All drain cocks, plugs or valves in the lowest parts of water pumps, coolers, piping and exhaust manifolds should be kept open. An inspection should be made to ensure that no water remains in pockets or low points in the engine water systems. Lubricating oil should be sprayed into the combustion space. After this, the engine should be turned over a few revolutions. The fuel oil valve between the fuel day tank and the engine should be closed. All openings leading from the outside to the engine must be sealed shut to prevent snow and moisture from entering. All air in the starting systems should be blown out to eliminate moisture and air tanks left charged at normal starting pressures. Mufflers and water traps in diesel exhaust system should be drained.

(2) *Boilers.* All watersides and piping should be completely drained and blown out with air. Drain cocks must be opened. The fuel oil manifold on the burner front should be disconnected, drained and then be tightly plugged. All openings such as smoke pipes, vents, drain connections, access doors, observation ports and other openings to the atmosphere should be covered and sealed to obtain the best possible leak-proofing. The water sides of all heat exchangers should also be drained and blown out with air.

(3) *Condensers.* The steam sides of condensers should be drained. Both sides to air ejectors to the inner and outer condensers (steel) should also be drained.

(4) *Auxiliary Equipment.* Auxiliary equipment which is not to be used should be drained. To prevent the formation of sludge, oil should be removed from the lubrication oil cooler.

(5) *Steam Turbine and Gears.* All accumulated water must be drained from pockets or low parts of the turbines.

The lubricating oil system and gears need no special preservation.

(6) *Steam Piping Systems.* All steam supply and drain valves in fuel oil heating systems to each fuel oil tank, after a system has been laid up, should be kept in a closed position. All steam drain valves and steam trap by-pass valves not required to be closed should be left open. Regulator valves, reducing valves, steam traps and other controls in piping systems which cannot be thoroughly drained and dried without dismantling, should be taken down, repaired, dried and reassembled.

(7) *Aviation Fuel System.* All salt water and gasoline must be pumped or drained from tanks and lines. The system should be charged with CO_2.

(8) *Water, Air and Flushing Systems.* Except where protected by anti-freeze solutions, all the water must be completely drained from the systems; where practicable they should be blown clear and dry by compressed air. All tanks in the system which are in a charged condition should be disconnected or otherwise isolated. Moisture must be removed from moisture traps and blown out of the entire air system. Shipboard toilets should be completely drained unless anti-freeze solutions are to be left in the traps. All traps, reducing valves and lines in the flushing system must be completely drained. All bilges and water accumulations should be wiped dry.

(9) *Sea Water Cooling and Suction Sea Chests.* These should be blown out with compressed air and an airlock maintained between the valve disc and sea water.

(10) *Stern Tube Bearing, Rudder and Propellers.* The salt water flushing connection in the stern tube bearing should be shut off or secured. All water from this system must be drained and the stern tube gland tightened up so there is no trickle of water, normally present for lubricating purposes. Propeller blades should be aligned so that they will suffer the least damage from future ice pressure. The rudder must be secured amidships.

k. Garbage and sewage disposal could become a problem and arrangements would be necessary to prevent effluent from accumulating alongside the ship creating a hazard to health and an unwelcome attraction to all manner of animal and bird life. The obvious solution is to construct heads ashore. The foregoing is specially applicable if the crew intends to remain onboard (or has no choice in the matter). Cutting a hole in the ice can be self-defeating as water will well up through it, spread out along the surface beside the ship and freeze. This flooding process, by elevating the ice surface in relation to the ship, would create difficulties.

NOTE: Guide or safety lines, for use during blizzards, should be rigged between the ship and any structures which may have been erected on the ice.

m. For obvious reasons, a minimum number of people should be left behind as a sea-guard to protect the ship, discourage possible looters and to prevent damage to machinery and equipment.

n. *Probably the greatest danger to a ship or camp wintering in the Arctic is fire.* With strong winds to spread it, and lack of water to fight it, fire can destroy a camp in short order. A ship's crew could be forced to take to the ice, and plans should be laid for just such an eventuality before it happens.

1716. SEARCH AND RESCUE

a. ATP 10 – *Search and Rescue Manual* – should be consulted for details concerning search and rescue procedures.

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ATP 17(A)

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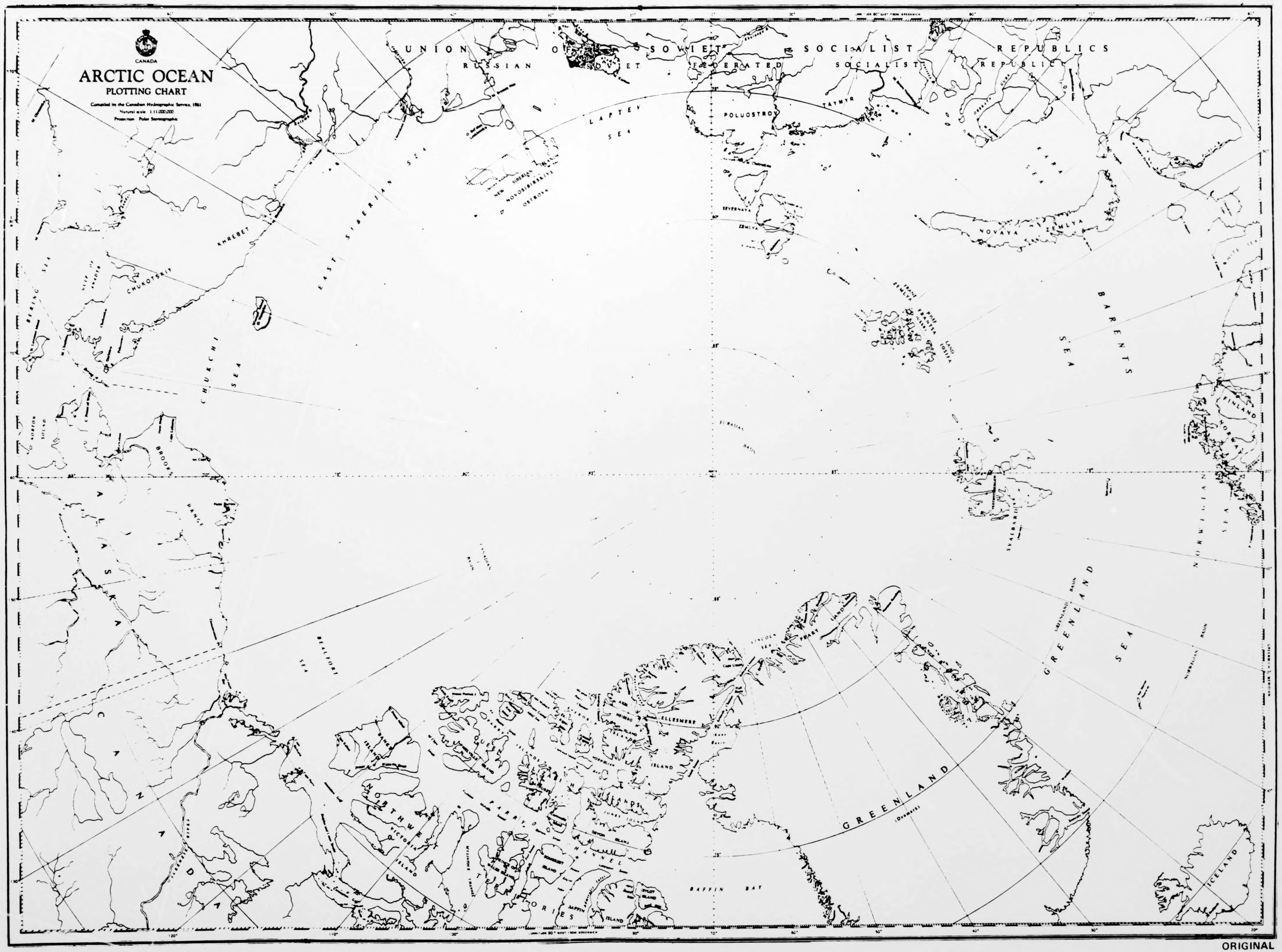
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